13th International Conference on Superplasticity in Advanced Materials

ICSAM 2018

Abstracts

August 19-22, 2018
St. Petersburg, Russia

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ICSAM 2018
St. Petersburg, Russia

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This book includes abstracts presented at the 13th International Conference on Superplasticity in Advanced Materials (ICSAM 2018), August 19-22, 2018, St. Petersburg, Russia.More than 200 researchers from academia and industry were coming together from 20 countries to report and discuss the recent advances on superplasticity and related issues.

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CONTENT

WELCOME TO ICSAM 2018

It is our pleasure to host the ICSAM 2018 – the International Conference on Superplasticity in Advanced Materials, in Saint-Petersburg, Russia.

ICSAM was established as a platform for academic researchers and industrial engineers in the field of superplasticity. Participants of this conference are involved in R&D activity in the field of material science and mechanical engineering.

The first ICSAM was held in San Diego in 1982. Thereafter, eleven conferences were held consecutively in Grenoble, Blaine, Osaka, Moscow, Bangalore, Orlando, Oxford, Chengdu, Seattle, Albi covering America, Europe and Asia. The last (12th) ICSAM held in 2015 in Tokyo, Japan, attracted more than 140 participants. ICSAM 2018 is the 13th International Conference on Superplasticity series and is built upon this proven concept and continues the tradition of its predecessors. Only a limited number of participants pay exclusive attention to the examination of superplastic phenomenon and the implementation of superplastic forming technique into commercial use. However, a majority of researchers examine different aspects of materials exhibiting superplastic phenomenon. Unique mechanical properties of materials with ultra-fine grained structure have been attracting significant attention of material science community.

The ICSAM 2018 provides a platform for discussing the production of materials with submicrometer and nanoscale grains, including all aspects of their mechanical behavior in addition to the superplasticity of materials. The overall aim of the ICSAM 2018 is to consolidate existing knowledge and identify future work requiring attention from the research of materials with fine and ultra-fine grained structure, their superplastic and other properties, and eventual commercial application.

In previous ICSAM conferences, members of the superplastic community were able to easily communicate which gave rise to fruitful discussions in superplastic activity. We believe that the spirit of the previous 12 ICSAM conferences will be continued successfully. The present ICSAM is organised by the Belgorod National Research University, in co-operation with Saint-Petersburg State University and Armalit31, a commercial company.

It will be our further pleasure for all the participants to obtain fruitful results through their presentation, discussion and information exchange, and to enjoy a social program as well as sightseeing tours before and after the conference. Saint-Petersburg, the old capital of the Russian Empire, will provide a variety of choices for the discerning tourist.

Rustam Kaibyshev
Chairman of National Program Committee
ICSAM 2018
Belgorod National Research University, Russia

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Co-Organization:

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Kenji Higashi	Osaka Prefecture University, Osaka, Japan
Megumi Kawasaki	Oregon State University, USA
Eiich Sato	JAXA Institute of Space and Astronautical Science, Sagamihara, Japan

Invited Speakers

Elena Astafurova	Laboratory of physics of structural transformations, Institute of Strength Physics and Materials Science, Siberian Branch of Russian Academy of Sciences, Russia
Jose Maria Cabrera	Departamento de Ciencia de los Materiales e Ingeniería Metalúrgica, EEBE – Universitat Politècnica de Catalunya, Spain
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CONFERENCE TOPICS

Superplastic materials and mechanisms of superplasticity

- Superplasticity in Metals and Alloys, Ceramics and Intermetallics
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- Cavitation and Fracture

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- Evaluation and Its Standartization

Industrial applications

- Superplastic Forming
- Diffusion Bounding
- Manufacturing Technologies
- Other Industrial Applications

ABSTRACTS

LEGEND

Type of participant Abstract No.

Title

Authors

Affiliation, Email

Abstract

#0073

Influence of the temperature of severe plastic deformation and annealing on the microstructure, mechanical properties and electrical conductivity of the Cu-Cr-Zr alloy

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Chromium bronzes are a special class of low-alloy copper alloys that combine high strength and electrical conductivity. However, modern applications require materials of ever higher properties of both strength and electrical conductivity. One of the modern actively proven methods of hardening is the severe plastic deformation (SPD). The application of an SPD by torsion (HPT) allows obtaining model samples with ultimate strength values. As has been shown in the case of aluminum alloys and steels, an increase in the deformation temperature can lead to a more stable state, due to the release of secondary-phase particles, segregations and clusters of impurity atoms. The influence of the temperature of the HPT on the microstructure, mechanical properties and their thermal stability is considered. So, as a result of HPT, a significant refinement of the microstructure occurred at room temperature, which led to an increase in strength up to 820 MPa, an increase in the deformation temperature led to a decrease in strength characteristics, which is related to the process of return upon deformation. With additional annealing, both the increase in strength properties up to 890 MPa and the electrical conductivity up to 70% of IACS are observed.

#0074

Direct and reverse martensitic transformations in AISI 321 steel during cryogenic and subsequent warm deformation

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Direct and reverse martensitic transformations in metastable austenitic steel of the AISI 321 type during cryogenic and subsequent warm rolling deformation have been investigated. It is shown that deformation with cooling in liquid nitrogen leads to intensive direct martensitic transformation. A decrease in the stacking fault energy of steel at cryogenic temperatures increases the number of alpha prime martensite nucleus, compared with deformation at room temperature. As a result, the lamellar structure of packet alpha prime martensite with the volume content up to 60% and deformation austenite microtwins are formed. In this structural state, the yield strength values reach 920-930 MPa with a relative elongation of 14-15%. Subsequent warm deformation with heating to 873 K contributes to the reverse martensitic transformation with the formation of the submicrocrystalline lamellar austenite structure. The volume content of austenite is about 72%. However, this treatment partially preserves the lamellar alpha prime martensite structure. In this structural state, the yield strength increases up to 1250 MPa at satisfactory values of the relative elongation. The deformation at T = 300-773 K (after cryogenic deformation) does not contribute to the reverse martensitic transformation, since the free energy change between martensite and austenite does not reach critical values. Subsequent annealing at 1073 K for 200 s after thermomechanical treatments reduces the volume content of alpha prime martensite in steel down to 5% and maintains the lamellar submicrocrystalline structure. The yield strength after annealing reaches 870 MPa at values of the relative elongation of 14-24%.

#00125

Formation of the nanostructure and mechanical properties during industrial technology of radial-shear rolling of the new aluminum alloy based on the Al-Zn-Mg-Fe-Ni system

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A high-strength aluminum alloy based on the Al-Zn-Mg-Ni-Fe system has been studied after radial shear rolling with (RSR) a total drawing coefficient of 8.16. To study the evolution of the microstructure during the deformation, microhardness measurements scanning and transmission electron microscopy and Electron Backscatter Diffraction (EBSD) were performed. Additionally, the distributions of the equivalent stress during deformation and the equivalent strain after processing were studied by finite element analysis using the commercial software QFORM. It is shown that RSR leads to the formation of a gradient microstructure with an ultrafine-grained surface layer with thickness of about 300 μm and a coarse-grained interior of the billet. The size of fine equiaxed grains in the ultrafine-grained surface layer varies in the range 1.0-15 μm. The results of uniaxial tensile tests revealed that the mechanical properties of the investigated alloy are comparable to the strength of a similar industrial alloy after equal channel angular pressing. A good correlation between the simulated equivalent strain distribution and the measured microhardness distribution was also demonstrated. Thus, it can be concluded that the radial-shearing rolling can be used for deformation processing of high-strength aluminum alloys and emerging gradient structure provides a high complex of mechanical properties.

#0079

Characterization of stress-strain behavior of superplastic titanium alloy by free bulging tests with pressure jumps

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The work is dedicated to determination of stress-strain behavior of Ti6Al4V alloy deformed in conditions of biaxial tension provided by free bulging testing. The dome height during each test was continuously measured and recorded using a magnetostrictive position transducer. All the tests were performed using stepped pressure regime with jump pressure changing between two values at evenly spaced time moments. This experimental technique provides the possibility to study strain rate sensitivity index variation during the test and subsequently construct strain and strain rate dependent material model. The output data of each test include the evolution of dome height, subsequent pressure regime and final thickness of the specimen at the dome pole. In the framework of this study the processing of such data in order to evaluate the material behaviour is discussed. Inverse analysis with different material models was implemented as well as special direct technique allowing one to construct stress-strain curves based on the results of free bulging tests with pressure jumps. The obtained material model was verified by finite element simulation.

#00123

In-situ observations of superplasticity in titanium alloys: rationalising deformation mechanisms

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Surface observations are used to elucidate the deformation mechanisms responsible for superplasticity in the Ti-6Al-4V and ATI 425 titanium alloys. First, stress relaxation tests and electrical resistivity measurements are used to quantify the difference in superplastic behaviour of each alloy: these estimate the strain rate sensitivity and the volume fraction of β as a function of temperature respectively. Then, high-temperature in-situ tensile tests are performed in the scanning electron microscope at 700, 800, and 900°C. Grain boundary sliding is found to be the main mechanism, accommodated by dislocation activity. Moreover, it is shown that the volume fraction of β plays a crucial role; a minimum volume fraction of β phase is needed so that cavitation is minimal and slip bands needed for dislocation-based accommodation are absent in α. For low β phase fractions, slip bands in α and cavitation are found to accommodate grain boundary sliding which triggers the formation of subgrains and dynamic recrystallisation, consistent with the Rachinger theory. In-situ observations are critical when elucidating the differences in superplastic behaviour for each one of the measured alloys and are useful to understand – with aim of optimising – the effect of chemistry on the superplastic effect in titanium alloys.

#00134

Effect of Multi-Directional Forging on Tribological Properties of Al-7Si-4Zn-3Cu Alloy

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In this study, dry sliding friction and wear properties of Al-7Si-4Zn-3Cu alloy was investigated at as-cast, homogenised and multi-directional forged (MDFed) in three, six and nine passes corresponding one, two and three cycles. The tests were performed by using a ball-on-disc type tribometer according to ASTM- G99 standards. A 100Cr6 steel balls with 6 mm diameter were used during tribological tests. Friction and wear tests were performed under a constant load of 5 N and at a sliding speed of 0.16 ms^{-1} for a sliding distance of 1000 m.
It was found that the friction coefficient and wear loss values increased with increasing multi-forging cycles. Amongst the samples, the highest friction coefficient and wear loss were obtained from the sample that forged with three cycles, while the homogenised samples showed the lowest wear loss value. Worn surfaces of all samples were characterized by smearing with some level of oxidation and delamination.
Wear test showed that the MDF resulted in a decrease in wear resistance of the Al-7Si-4Zn-3Cu alloy in spite of increasing its tensile and yield strength and ductility. The decrease in wear resistance of the alloy after MDF may be related to thermal softening caused by frictional heating taking place on the sample surface during wear test.

#00158

Effect of the level of accumulated strain on the hardening behavior in a chromium bronze

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A Cu-Cr-Zr alloy was subjected to severe deformation by HPT at room temperature under a load of 6 GPa. The diameter of the samples was 10 mm. Prior to the deformation, the samples were subjected to long-term aging at 450 °C for 4.5 hours, with a view to produce an extremely low concentration of solid solution in the copper matrix. It has been found that the above-mentioned quantities vary depending on the level of accumulated strain. It has been established that under an accumulated strain of e=314 (4 rev.), the maximum growth of strength characteristics is observed, while electrical conductivity is preserved at its initial level. By the 4th revolution, a significant structure refinement takes place. During subsequent deformation, no further refinement occurs, and precipitation of ultrafine second-phase particles with a size of about 10 nm is revealed. At the same time, under an accumulated strain of e=471 (6 rev.) strength visibly decreases by 20% and electrical conductivity decreases by 15%. Ultrafine particles with a size of about 10 nm are not observed in the matrix, and the density of coarser particles declines.
The obtained data indicate that the accumulated strain under a hydrostatic pressure of 6 GPa during HPT processing has an effect on the quantitative changes in the phase composition of the Cu-Cr-Zr alloy and can serve as a criterion for controlling the physico-mechanical properties of precipitation-hardenable low-alloyed bronzes in the process of SPD.

#0066

Mechanical Properties of Multi-Directional Forged Al-7Si-4Zn-3Cu Alloy

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In this study, Al-7Si-4Zn-3Cu alloy was processed by multi-directional forging (MDF) and its structural and mechanical properties were investigated. For this purpose, the samples with a dimension of 40x40x20 mm prepared from as-cast alloy were homogenized at 450 °C for 24 h. The MDF was performed by a hydraulic press having a capacity of 150 tons with an open die which has two free deformation axes at 200 °C and plunger speed of 1 mm/s. The samples were multi-directional forged in three, six and nine passes corresponding one, two and three cycle respectively at a strain of 0.69 in a single pass.
The MDF resulted in a severely deformed and refined microstructure with eliminated casting defects like micro-porosity and formation of nearly homogeneous distributed finer silicon particles. The strength values of the alloy increased up to two cycle, above which they showed a decrease, while the elongation to fracture increased significantly as the cycle number increased. In addition, processed samples exhibited higher tensile and yield strength and elongation to fracture than those of as-cast and homogenised alloys.

#0031

Simulation of Deformation Behavior and Microstructure Evolution during Hot Forging of TC11 Titanium Alloy

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Finite element method is the most powerful tool for development and optimization of the metal forming processes. Analysis of titanium alloy critical parts should include the prediction of microstructure, since their mechanical and technological properties essentially depend on the type and parameters of the microstructure. The technological process of parts production for aerospace applications is multi-operational and consists of deformation, heating and cooling steps. Therefore, it is necessary to simulate the microstructure evolution to obtain high quality parts. In this paper FE simulation coupled with microstructure evolution during hot forging of TC11 titanium alloy has been performed by QForm FEM code. Constitutive relationships, friction conditions and microstructure evolution model have been established based on the experiments. The kinetics of phase transformations has been described by the Johnson-Mehl-Avrami-Kolmogorov (JMAK) phenomenological model. The approach is illustrated by industrial case study that proved its practical applicability and economic advantages for technology development of titanium alloy critical parts.

#006

Pressure Dependence of the Electrical Conductivity of MGa_2S_4 and $M_2Ga_2S_5$ (M – Fe, Pb, Ni)

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Practically important materials such as AB_2X_4 are a family, usually with magnetic and optical properties. Investigations of the magneto-optical effect in MCr_2S_4 (M = Mn and Fe) with a spinel structure showed that in $FeCr_2S_4$ a giant magneto-optical response reaches up to 4.3°. The pressure greatly affects the magnetic and transport properties of $FeCr_2S_4$. At a pressure of 8 GPa, a break in the temperature dependence of the resistivity is observed in $FeGa_2S_4$. This effect is explained by the transition from a two-dimensional frozen state with spatial separation to a three-dimensional spin-ordered state (Tomita T. et al., 2009). In $FeGa_2S_4$ as well as in $Fe_2Ga_2S_5$, there is no transition to the metallic state in the pressure range up to 8 GPa. The resistivities of both $FeGa_2S_4$ and $Fe_2Ga_2S_5$ decrease with increasing pressure at room temperature. The $FeGa_2S_4$ energy gap, estimated from the temperature dependence of the resistivity, shows a negative pressure dependence. A characteristic feature of the conductivity dependence of $NiGa_2S_4$ and $FeGa_2S_4$ compounds on the pressure at 300 K is that the conductivity increases with increasing pressure. The band gap of $NiGa_2S_4$ and $FeGa_2S_4$ decreases with increasing pressure.

#00142

Relationship between the parameters of deformation site and the intensity of structure refinement in copper during rotary forging

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In the process of study of the deformation site during rotary forging (RF), we analyzed the complex stress-strained state of a copper billet in the context of the intensity of structure refinement. Taking into account the dominant role of the strained state in the refinement of structural elements, we optimized the geometrical parameters of the deforming tools by the finite element method, with a view to increase the accumulated strain during RF. We established that the optimized forming tool provides an accumuluated strain of e~1 in just one processing stage, while the conventional processing by rotary forging provides such a level of accumulated strain in 2-3 stages. We calculated the Lode-Nadai coefficient, which is a criterion for the degree of non-monotony and the realized pattern of stressed state in the deformation site. We performed a quantitative microstructural analysis.
The authors gratefully acknowledge the financial support from the Ministry of Education and Science of the Russian Federation under Grant agreement No. 14.586.21.0025 (unique identification number RFMEFI58616X0025).

#0057

On the Hall-Petch effect in austenitic stainless steels

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Influence of grain size on mechanical properties (in particular, yield strength) of AISI 302, AISI 316L and AISI 321-type austenitic stainless steels was investigated. Wide range of grain sizes in above mentioned steels were obtained by multiple bar rolling at room temperature to a total strain of 80% with following annealing at temperatures of 650-1050^{o}C. It was established that decrease in grain size leads to increase of strength properties of austenitic stainless steels under consideration. Analysis of dependences of yield strength on the grain size showed that obtained results obey Hall-Petch relationship with high correlation coefficient (about 0.99). It is also shown that increase of carbon concentration leads to increase in Hall-Petch coefficient (k_{HP}) from ~300 MPa·mkm$^{-1/2}$ for AISI 316L steel to 1000 MPa·mkm$^{-1/2}$ for AISI 302 one. It should be noted, that steel with low carbon concentration (AISI 316L) demonstrates dependence of Hall-Petch coefficient on the strain rate. Particularly, increase in strain rate from 10^{-4} to 10^{-3} results in decrease of k_{HP} from 338 to 274 MPa·mkm$^{-1/2}$.
This study was supported by the Program of Fundamental Researches of the State Academies of Sciences for 2013-2020 (project 23.2.6).

Invited #0068

Hydrogen embrittlement of the ultrafine-grained austenitic stainless steels

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We studied the effect of electrolytic hydrogen-charging on the regularities of plastic flow, strength properties, plasticity and fracture mechanisms in three austenitic stainless steels (AISI 302-, 321- and 316-type) with different stacking fault energies. In the steels, the ultrafine-grained structures of various morphologies (ultrafine-grained, misoriented subgrain and mixed grain/subgrain) were produced by the hot ABC-pressing and thermomechanical treatments including cold rolling and annealing at 600-650ºC. The strength properties of ultrafine-grained steels are 3.5 to 6 times higher than those of quenched steels with coarse-grained structures.
Electrolytic hydrogen-charging contributes to the reduction of the yield strength irrespective of the grain/subgrain size, composition of the ultrafine-grained steels and their stacking fault energies. In comparison with coarse-grained counterparts, the formation of a highly defective subgrain structure with a high dislocation density and low-angle misorientations suppresses the hydrogen embrittlement in 316 and 321 steels, in which a small volume fraction of strain-induced alfa'-martensite is formed under tension. The formation of mainly high-angle grain boundaries in stable 316 steel, contrarily, contributes to the enhancement of the hydrogen embrittlement in comparison with those that possess a grain/subgrain structure with a high dislocation density and small-angle boundaries. The greatest effects of hydrogen embrittlement are characteristic of ultrafine-grained 302 and 321 steels with a predominantly grain structures, which undergo gamma→alfa'-phase transformation under tensile deformation.
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#00172

Inhomogeneous precipitation of the α-phase in Ti15Mo alloy processed by ECAP

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In this study, Ti15Mo, a metastable beta titanium alloy was subjected to equal channel angular pressing (ECAP). The microstructure of specimens after different ECAP passes was observed using scanning electron microscope (SEM). Transmission electron microscopy measurements revealed high concentration of stress-induced ω-phase by deformation. Nevertheless, the deformation is not sufficient for achieving homogenous ultra-fine grained structure. In-situ resistivity measurements proved that precipitation of the α-phase is accelerated in the materials after severe plastic deformation. For clarification of the effect of the deformation on the phase transformation in metastable beta titanium alloy number of experimental methods were used. In-situ SEM during annealing showed that in part of the material with higher concentration of lattice defects the α-phase precipitates easily. The deformed structure after annealing consisting α, β and ω-phase was studied by the advanced method of transmission electron backscattered diffraction (tEBSD).

#002

Mesoscopic scale modeling of superplastic flow in geological and glacial materials

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A viewpoint that suggests that grain/ interphase boundary sliding (GBS) that develops to a mesoscopic (i.e., of the order of a grain diameter or more) scale ("cooperative boundary sliding") controls optimal superplastic deformation has already been shown to explain superplasticity in metals and alloys, ceramics, intermetallics, composites, bulk metallic glasses etc. of grain sizes ranging from a few microns to a few nanometers rather well. In this paper it is used to describe structural superplasticity in minerals, rocks and ice. The accommodation process depends on the experimental conditions, chemical composition, microstructure and the nature of the GB obstacles. It could either be dislocation emission from sliding boundaries or highly localized diffusion, which is much easier than Coble diffusion. Analysis shows that optimal structural superplasticity in geological and glacial materials can be accounted for in terms of four "universal" constants of values, gamma_0 (average strain associated with a basic boundary siding event) = 0.197, gamma_B (specific grain boundary energy, which is assumed to be isotropic) = 0.415 Jm^{-2}, N (number of boundaries that align themselves to form a plane interface) = 8.9 and "a" (a constant that lies between 0.1 – 0.5) = 0.166. It is demonstrated that with the help of these four "universal" constants and the Frost-Ashby equations for estimating the shear modulus of a material, it is possible to predict accurately steady state superplastic flow in geological or glacial materials, including those whose superplastic behavior was not included in the analysis for generating the "universal" constants.

#00147

Modeling of grain size in shape memory alloys, microstructural approach

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Shape-memory alloys capable of a superelastic stress-induced phase transformation and a high displacement actuation have promise for applications in medicine and engineering. Recent experiments show the dependence of mechanical properties of these materials on the grain size. This fact should be taken into account in the calculations for the design of devices with elements of these alloys. The main purpose of this work was the theoretical description of the influence of grain size on the mechanical behavior of shape memory alloys in framework of microstructural model. That model was used for calculation of the effect of grain size on the deformation of shape memory alloys and obtained results are in qualitative agreement with experiment. The results of numerical experiments show an increase of the critical stress for the stress-induced martensitic transformation with a decrease in grain size, according to the power law.

#00196

Production of Ti-Sheet Metal Parts. Is SPF still in key position?

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Cold forming of Ti-alloy sheet metal parts is not really possible because the forces are very high, the achievable strain is rather low, especially if strain in two axis is necessary and the springback is not really predictable. It is well known that hot forming processes are much better suited to obtain complex shape and precise contour. SPF-properties of Ti-alloys allow very large strain, not possible with any other sheet metal forming process. Over the years the community saw splendid applications. With more experience the drawback of physically defined low strain got important, even with countermeasures like the introduction of micrograin material, better adopted pressure/time curves etc. With higher quantity production the high cost level started to play a more important role. Based on this situation and on the constant increase of business volume and the part quantity in the aircraft industry newer technologies like hot deep drawing have been developed, also possible in combination with SPF for some special applications. These processes are more suitable for higher production rates and offer significant cost savings because the material input is much smaller, the cycle time much shorter and the post-processing with chemical cleaning of oxidized surfaces takes much less effort. Despite this new upcoming hot forming production process, SPF plays still an important role, but for a tighter spectrum of parts which can be clearly identified.

#00200

Effect of Zirconium Additive on Deformation Behavior and Electroconductivity of Aluminum Alloy

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The microstructure and properties of the Al−Zr alloys after heat treatment were investigated. The aluminium alloys with different Zr content were melted in an electric furnace in graphite-chamotte crucibles. The alloys were annealed in a wide temperature range (300-600°C) during one hour. The metastable Al_3Zr precipitations with $L1_2$ structure in the Al-Zr alloys were detected after annealing. The particles size depended on heat treatment temperature. In a peak aged condition the average size of Al_3Zr-particles was 10-20 nm. The deformation behavior of all samples was characterized by low flow stresses, large strain hardening and large uniform elongation. It was found that electroconductivity depended on the phase composition. A modified Hall-Petch relationship was applied to analyze the contributions of particle strengthening to the yield strength. The effect of zirconium addition on deformation behavior and strengthening was discussed.
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#00103

Microstructure of aluminium Al-Zn and Al-Zn-Mg-Cu alloys after high pressure torsion

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It has been shown in this work that processing by severe plastic deformation leads to the formation of a UFG structure with a grain size of below 500 nm in aluminium alloys. The supersaturated solid solution in Al alloys is decomposed during HPT processing resulting in nucleation and growth of a secondary phase precipitates and/or formation of segregations of alloying element Zn. It is proposed that the atomic mobility could be significantly enhanced during SPD especially thanks to the high vacancy concentration, solute drag by dislocations, pipe diffusion along dislocations or grain boundary diffusion. The mechanical tensile tests at room temperature show that studied Al alloy demonstrates a superductility, which is unusually high for the low temperature state.
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#00111

Atomic structure evolution of Zr-based bulk metallic glass processed by severe plastic deformation

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Bulk metallic glasses (BMG) are subject of great scientific as well as potential practical interest due to their unique mechanical properties including high strength, large elastic elongation along with low Young's modulus [1]. However, their possible applications are strongly limited by their brittleness at room temperature. Last several years numerous efforts were made with the aim to improve ductility of metallic glasses. It was shown that preliminary plastic deformation processing (compression, cold rolling or high-energy ball milling, etc.) can leads to increased ductility of BMG by nucleation and branching of multiple shear bands, which contribute to overall plasticity [2]. In this regard, high pressure torsion (HPT) seems to be a promising method for BMG ductility improvement due to high deformation degree of HPT even for brittle and hard to deform materials [3]. The $Zr_{62}Cu_{22}Al_{10}Fe_5Dy_1$ bulk metallic glass was subjected to HPT at different temperatures. Structural investigations were performed using XRD, DSC, TEM. Mechanical testing was performed using uniaxial tension tests, nanoindentation. Examination of structural and mechanical properties demonstrates significant changes in properties of bulk metallic glass after HPT processing in comparison with the initial state.

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Invited #00184

Novel method of severe plastic deformation - continuous closed die forging: CP aluminum case study

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There is a large number of methods for severe plastic deformation (SPD). Multidirectional forging (MDF) is probably one of the most easily scalable for industrial application. In general, there are two main conditions for SPD processing: constant sample geometry and application of a quasi-hydrostatic pressure. The first condition is necessary for strain accumulation by repetitive deformation and the second one helps preventing cracking in the specimens with high accumulated strain. However, MDF is not providing quasi-hydrostatic condition in the processed sample. This paper reports a novel method for severe plastic deformation, namely continuous close die forging (CCDF), which fulfils both requirements for the successful deformation of samples to a very high accumulated strain. Commercially pure aluminum (1050) was processed to a total strain of 24 by CCDF. After processing, the microstructure was refined down to a mean grain size of 0.5 µm. Tensile testing showed good mechanical properties: yield strength and ultimate tensile strength of the ultrafine-grained aluminum were 180 and 226 MPa, respectively. Elongation to rupture was about 18%. The microstructure, microhardness and grain boundary statistics are discussed in relation to the high mechanical properties of the UFG aluminum processed by the novel method.

Keynote #0023

Superplasticity of aerospace 7075 (Al-Zn-Mg-Cu) aluminium alloy obtained by severe plastic deformation

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The 7075 (Al-Zn-Mg-Cu) aluminium alloy is the reference alloy for aerospace applications due to its specific mechanical properties at room temperature, showing excellent tensile strength and sufficient ductility. However, from an industrial point of view, it is highly convenient to increase the formability at high temperatures. This is achieved by obtaining superplasticity in the alloy as a result of fine, equiaxed and highly misoriented grains prone to deform by grain boundary sliding (GBS). Different severe plastic deformation (SPD) processing routes such as ECAP, ARB, HPT and FSP have been considered and their effect on mechanical properties, especially at intermediate to high temperatures, are studied. Refined grains as low as 150 nm and average misorientations as high as 39º allow attainment of high strain rate superplasticity (HSRSP) at lower than usual temperatures (250-300ºC). It is shown that increasing misorientations are obtained with increasing applied strain, and increasing grain refinement is obtained with increasing processing stress. Thus, increasing superplastic strains at higher strain rates, lower stresses and lower temperatures are obtained with increasing processing strain and, specially, processing stress.

#0055

The study of the mechanisms of deformation of ultrafine-grained and nanocrystalline TiNi alloys at different test temperatures

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The study were carried out on TiNi alloys and on commercially pure Ti Grade-4. Ultrafine-grained (UFG) state was obtained on TiNi alloys by used ECAP. The NC state was obtained by intense plastic deformation by torsion followed by annealing. According to the data obtained in the coarse-grained (CG) state, the grain size of the $Ti_{49.4}Ni_{50.6}$ alloy is 50 μm, grain boundaries and triple grain joints free of dislocations (TEM) are observed. The $Ti_{50,0}Ni_{50,0}$ alloy is in the martensite state has a predominantly morphology of pairwise twinned lamellar crystals, which are twins of the type (111) and $(011)_{B19'}$ (h_M=85±15 nm). The ECAP leads to the transformation of the initial structure into a UFG structure with an increased density of dislocations in the $Ti_{49.4}Ni_{50.6}$ alloy (D_A=300±20 nm), a complex martensitic structure in the material in the alloy $Ti_{50.0}Ni_{50.0}$ (D_M=600±30 nm), inside which there are twins with a plate width h_M=79±8 nm. In the range of deformation temperatures by stretching of 20°-400°C, the values of the dislocation yield strength and the ultimate strength of the UFG state of the alloy are higher than the CG states. Tests at various temperatures showed the strength and ultimate strength limits decrease in both alloys in all the investigated states with increasing test temperature. As a consequence, the tensile strength increases from 750 MPa in the CG condition to from 1000 MPa in the UFG (ECAP-Conform) state and 1200 MPa in the HC (ECAP-Conform+drawing) state with the grain size reduction in the Ti Grade-4.

#0045

Analitical modelling of strength and electrical conductivity of nanostructured Cu-Cr alloys

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Purposeful formation of nanostructured metallic materials due to severe plastic deformation having high strength combined with high electrical conductivity is an important scientific and practical task. For its solution it is necessary to identify the degree of influence of nanostructured elements introduced in the process of such deformation and subsequent thermomechanical processing on strength and electrical conductivity. Results of a research by methods of analytical modeling of strength and conductivity of the Cu-Cr alloys depending on the presence of such defects of a crystal lattice as the vacancies, atoms dissolved in a matrix, dislocations, particles of a secondary phase, nanotwins are given in the presented work. Results of the assessment of the contribution of each of them in strength and electrical conductivity of the material are given. The optimum combination of the structural elements resulting in the increased values of the studied properties is revealed.

Invited #00186

Superplasticity in metals: comparison with ceramics and high entropy alloys

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While most early studies on superplasticity focussed on metallic materials, more recent studies have demonstrated that the phenomenon is general and observed also in a wide range of intermetallic compounds, composites, ceramics, nano and ultrafine grained materials, and high entropy alloys. Although the phenomenology in terms of high ductility and high strain rate sensitivity are common, it is not clear whether the underlying rate controlling deformation mechanisms remain the same. In metals, superplasticity is generally attributed to grain boundary sliding and its accommodation by the injection of intragranular dislocations into a grain and the climb of such dislocations at the opposite boundary. However, intragranular dislocation motion is difficult in ceramics, giving rise to the possibility of different rate controlling mechanisms in metals and ceramics. This presentation will critically evaluate the rate controlling mechanisms in ceramics and high entropy alloys, based on an understanding of superplasticity in metals.

#00164

The influence of processing by severe plastic deformation on the microstructure and properties of amorphous alloy and metallic glasses

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Previous studies have shown that the severe plastic deformation (SPD) technique of high pressure torsion (HPT) essentially transforms the structure of amorphous materials, but the regularities of these transformations are far from being clear. For instance, in the amorphous melt-spun (MS) TiNiCu alloy during HPT processing there occurs nanocrystallization, and also a specific amorphous nanocluster-type structure forms. In the presented work, we performed additional studies on the effect of HPT processing on the microstructure and properties of amorphous alloys, in particular, the TiNiCu alloy and Zr-based BMG. The HPT processing was conducted at room temperature and at a temperature of 150 °C with different numbers of revolutions. Structural characterization of the HPT-processed samples was performed using transmission electron microscopy, XRD, DSC. In addition, nanoindentation was conducted in order to determine the modulus of elasticity and hardness. In our report, we present new data on the changes in the microstructure and properties of the given amorphous alloys as a result of HPT processing.

#00165

Microstructures and mechanical properties of the $CoCrFeMnNiN_x$ high entropy alloys

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The CoCrFeNiMn alloy is typical high entropy alloy (HEA) with excellent plasticity and fracture toughness. However, the strength is quite low. In this paper, different N contents (N=0, 0.05, 0.1, x as the molar ratio) were added to CoCrFeNiMn alloy to improve the strength of this alloy. The HEA ingots were hot forged, and subsequently homogenization annealing. Then, the homogenized samples were subsequently cold-rolled respectively to 40% 60% and 80% and finally annealed at 800℃. The samples were abbreviated as R40, R60 and R80, respectively.
The results show that the addition of N can strengthen the HEAs remarkably without dramatically sacrifice of the ductility. Compared with N0-40% alloy, the N0.05-40% alloy has yield strength of 420MPa, while N0.1-40% alloy has yield strength of 476MPa. In addition, N0.1-40% alloy also shows the excellent tensile ductility(~38.8%). An increase in N contents can strengthen of the HEAs further. The ductility decreased very little for the Nx-60% alloys. Compare with the ductility of the N0-60% (42.5%), the ductility of the N0.05-60% alloy and the N0.1-60% alloy is decreased respectively to 41.3% and 38.8%. The tensile strength of the N0.1-80% alloy reaches the maximal value of 906 MPa with ductility of 28.3%.

#00146

Effect of Long-Term Natural Aging on Room Temperature Superplasticity of Zn-Al Alloys

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Zn-22Al and Zn-0.3Al alloys were processed through equal-channel angular pressing/extrusion (ECAP/E) in order to achieve high strain rate (HSR) superplasticity at room temperature (RT). ECAPed samples of both alloys were then subjected to aging at RT for 1100 days to evaluate the effect of long-term natural aging on their microstructural stability and superplastic behavior. Before natural aging, the maximum elongations to failure at RT were 400% for ultrafine-grained (UFG) Zn-22Al at the strain rate of $5x10^{-2}$ s^{-1} and 1000% for fine-grained (FG) Zn-0.3Al at the strain rate of $1x10^{-4}$ s^{-1}. Long-term natural aging did not cause a significant change in the elongation of UFG Zn-22Al alloy with 355% maximum elongation. However, optimum strain rate giving the maximum elongation decreased to $3x10^{-3}$ s^{-1} after long-term natural aging. Natural aging of FG Zn-0.3Al alloy for 1100 days resulted in a significant decrease in elongation to failure. Maximum elongation decreased down to 450% in Zn-0.3Al after the natural aging process. The difference between thermal stabilities of two Zn-Al alloys was explained in terms of their different phase compositions and microstructural characteristics.

#00127

Superplasticity in fine grain Ti-6Al-4V alloy: mechanical behaviour and microstructural evolution

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Superplastic forming (SPF) is an expensive process requiring high temperatures and low strain rates. Several studies deal with the decrease of its cost by improving the formability of materials at lower temperature, in particular, using refined microstructure. Titanium Ti-6Al-4V alloys are known to exhibit interesting superplastic properties. Moreover different deformation and accommodation mechanisms might be involved during SPF depending on the grain size, the temperature, the strain rate and, for the Ti-6Al-4V, on the phase fraction (alpha/beta).
This study focuses on the mechanical behaviour and the microstructural evolution for a wide range of temperature (750°C-920°C) and strain rates (10^{-2} s^{-1}-10^{-4} s^{-1}) of a fine grain Ti-6Al-4V (d_{alpha} = 3 micrometer). For the lowest temperature, results are compared with an ultrafine grain Ti-6Al-4V alloy (d_{alpha} = 0,5 micrometer). Additional static tests with different temperature exposure times similar to tensile tests duration were done to investigate the "static" and "dynamic" grain growth. To study more precisely the microstructural evolution, interrupted tensile tests were conducted.
SEM observations with image analyses allow the study of the evolution of grain size with the temperature and deformation. Under 920°C, the obtained grain growth can be related to the slight hardening observed on stress-strain curves. The phase fraction evolution versus the temperature was also assessed and confirmed that for temperatures within the range of 850°C-920°C the beta phase may have a contribution on superplasticity. These data associated with XRD and EBSD analyses allow discussion of the two phase's texture evolution and accommodation mechanisms during high temperature straining.

#00119

Grain refinement of Ti-6Al-4V alloy processed by friction stir processing and enhanced low temperature superplasticity

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A cold-rolled Ti-6Al-4V sheet was subjected to heat treatment at 1010 °C for 1 h and cooled in water, followed by further annealing at 550°C for 3 h and subsequent air cooling to room temperature. The fully lamellar structure was obtained and then processed by friction stir processing (FSP) at a tool rotation rate of 120 rpm with a tool traverse speed of 30 mm/min, after which fine equiaxed alpha grains with a size of ~0.5μm and a small amount of beta phase were obtained. Superplastic tensile tests in the present FSP-processed Ti-6Al-4V alloy were conducted in the strain rates range from 1×10^{-2} to 1×10^{-4} s^{-1} at 650°C. All the specimens exhibited superior low temperature superplasticity except for the specimen deformed at 1×10^{-2} s^{-1} with an elongation of 350% and the optimal superplasciticy with an elongation of 1220% was achieved at 1×10^{-3} s^{-1} and 650°C. The superplastic deformation mechanism appears to be grain boundary sliding accommodated by grain boundary diffusion.

#0067

Mechanical and in-service properties of magnesium alloy WE43 after equal-channel angular pressing

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Magnesium alloy WE43 is a promising biodegradable material for medical application and increasing its mechanical and in-service properties is an important task. Equal-channel angular pressing (ECAP) allows to efficiently address both aspects of the property profile of the alloy. In this work we examined the structure, texture, mechanical and corrosion properties and fatigue behaviour of WE43 after ECAP. Route Bc ECAP was conducted with a stepwise decrease of temperature from the initial level of 425°C to 300°C at the final step. The total number of passes was 12 (the cumulative equivalent strain ~7.8). The formation of an ultrafine-grained (UFG) structure with a grain size of ~ 0.7 μm led to an increase of strength to 300 MPa, which compares favourably with 220 MPa in the initial state of the alloy. At the same time, the transformation of the basal texture to a prismatic one resulted in an increase in ductility from 10.5% in the initial state to 12.4% after ECAP. It should be noted that ECAP-induced grain refinement did not affect the resistance to electrochemical corrosion, but did reduce the chemical corrosion rate. The corrosion rate measured in a 0.9%NaCl solution dropped from 0.93±0.20 mg/cm^2*day in the initial state of the alloy to 0.52±0.09 mg/cm^2*day after ECAP. The formation of UFG structure also had a positive effect on the fatigue resistance of the alloy, increasing the fatigue limit from 90 MPa in initial state to 140 MPa after ECAP.
This research was supported by the Russian Science Foundation (grant #17-13-01488).

#001

Microstructure Evolution of a High-Nitrogen Austenitic Stainless Steel during Hot Working

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Dynamic recrystallization (DRX) is one of most prominent mechanisms for control of microstructure in various metals and alloys. The dynamic process of grain evolution in the austenitic stainless steel was studied in compression tests. The tests were carried out to a strain of ∼ 0.4 at temperatures ranging from 1073 to 1323 K and a strain rate of 10^{-3} s^{-1}. The multiple compressions with changing the loading direction in 90^{o} and decreasing the temperature with a step of 50 K from 1323 to 1073K in each pass were utilized to achieve large cumulative strains. The flow stresses increased in each subsequent compression. The size of the structural elements decreased with decreasing the deformation temperature, approaching a submicrometer scale level at 1173 K. Multiple compression led to a significant increase in the strength properties. The following properties were achieved after the total true strain of 2.4. The tensile strength is 1160 MPa, the yield strength is 990 MPa, and total elongation is 13%. The thermo-mechanical treatment consisting of multiple compressions with decreasing temperature is an effective method of grain refinement in austenitic stainless steel, providing remarkable improvement of the mechanical properties.

#0099

Microstructure evolution and mechanical behavior of titanium alloy VT8M-1 with globular-lamellar structure processed by equal-channel angular pressing

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The work is devoted to the study of recrystallization development and microstructural evolution of the coarse-grained Ti-5.7Al-3.8Mo-1.2Zr-1.3Sn alloy (the so-called VT8M-1) during severe plastic deformation via equal-channel angular pressing (ECAP). The analysis of mechanical behavior of the VT8M-1 alloy in a range of the deformation temperature from 650 to 800° C has been made. The evolution of the plate-shaped and globular α-phase during plastic deformation is examined. It has been demonstrated that as the number of ECAP passes increases from 2 to 6, the transformation of the alloy's microstructure proceeds via fragmentation of the lamellar constituent with its subsequent spheroidization. As a result of 6 ECAP passes, the alloy's initial lamellar constituent has transformed into the globular one, while the grains of the primary α-phase have retained the initial size and have been deformed with formation of dislocation cells. The thermomechanical treatment of the VT8M-1 alloy with application of ECAP has led to formation of the ultrafine-grained (UFG) structure with the size of the recrystallized particles about 0.6 μm. The investigation includes an examination of the effect of microstructure on the mechanical properties of the alloy.

ACKNOWLEDGMENTS
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#00151

Mechanical Properties and Microstructural Features of High-Strength Low-Carbon Steel Processed by Warm Tempforming

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Nowadays, high-strength low- carbon steels are widely used materials due to their low cost and good combinations of strength, ductility and toughness. However, this type of steels with high strength typically exhibits low Charpy V-notch impact energy of 10 to 40 J at lowered temperatures. Such low toughness often limits their structural applications. Structural steels have to be both strong and tough. These steels could not be used at temperatures below the ductile-brittle transition temperature (DBTT), at which the steel loses its toughness and fracture occurs in a brittle mode. One of the most promising way to increase the toughness and decrease DBTT of low-alloyed steels is tempforming, accompanied by the formation of an ultrafine grained structure.
The effect of the warm tempforming on the microstructure and mechanical properties of high-strength low-carbon S700MC-type steel was investigated. The tempforming resulted in the development of ultrafine grained elongated grain microstructure with the transverse grain size of 530 nm. The tempformed steel exhibited the ultimate tensile strength of 1110 MPa and the impact toughness, KCV, above 450 J/cm^2 at a temperature of 293 K, and KCV of 109 J/cm^2 at liquid nitrogen temperature for impact direction perpendicular to rolling plane. The enhancement of toughness was associated with delamination cracks which occurred in the ultrafine elongated grain structure with anisotropic properties.

#0019

Fatigue of Ultrafine Grained Al5083

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Ultrafine grained Al 5083 alloy was prepared by ECAP (6 passes, following route Bc at 150°C) from an extruded bar. The fatigue behaviour of the ultrafine and coarse grained materials (UFG and CG, respectively) were investigated in the low-cycle regime, through plastic-strain-controlled push-pull tests, and the high-cycle regime, through stress-controlled push-pull tests. Tests in the giga-cycle regime (using an ultrasonic testing device for repeated tension at 20KHz) are being prepared. SEM and AFM observations of the outer surface and fracture surface of the samples were performed to analyse the damage mechanisms. A strong cyclic hardening was observed in the CG material, while the UFG material showed a moderate cyclic hardening, followed by a steady-state. Constitutive equations were identified. In both materials, kinematic hardening was much more pronounced than isotropic hardening (by a factor of three for CG, five for UFG, where the dislocation density could probably not rise much, leading to a modest isotropic hardening). While for a given stress amplitude, the UFG material had a better resistance to LCF than its CG counterpart, their resistance were similar for a given strain amplitude. A few persistent slip bands were observed in the largest grains of the UFG material, but broken or debonded intermetallic particles were most often responsible for crack initiation. For the same plastic strain range, secondary cracks were much more numerous, but shorter, in the UFG material, this suggesting easier crack initiation, maybe due to the higher stress range, more favourable to the fracture of intermetallic particles.

#00100

Investigation of strengthening mechanisms of ultrafine-grained structure in titanium during ECAP-Conform

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The structural evolution and the process of formation of ultra-fined grained structure in commercially pure titanium (CP Ti) during severe plastic deformation via ECAP-Conform technique were studied. The 3D pattern of the structural evolution in the course of increasing the number of ECAP-Conform passes was plotted with the help of the method of back-scattered electron diffraction. The development of the deformation mechanisms and evolution of grains of deformational origin in titanium during SPD were analyzed, taking into account features of the plastic flow during the ECAP-Conform process. The detailed quantitative analysis of crystallographic parameters of boundaries and sizes of structural elements in the longitudinal and cross sections of the billet after ECAP-Conform was made. It has been demonstrated that the structural evolution in CP Ti during ECAP-Conform occurs by stages. The severe plastic deformation of CP Ti via the ECAP-Conform technique to the strain value of 8.4 has provided formation of the structure with the average grain size of 0.3 μm and the share of high angle boundaries 55%. On the basis of the detailed microstructure characterization, strengthening mechanisms of ECAP were elucidated.

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Invited #00121

Transition from low-temperature superplasticity to room-temperature superplasticity by high-pressure torsion

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Superplasticity, the capacity of a material to be deformed over 400% under tension, occurs only at high homologous temperatures, where grain-boundary sliding becomes the dominant deformation mechanism. It was shown that low-temperature superplasticity is achievable by formation of ultrafine grains (UFG) via severe plastic deformation (SPD), but the homologous temperature to achieve the superplasticity in UFG materials is still over 0.5 (e.g., 523 K for aluminium alloys and 473 K for magnesium alloys). One effective approach to achieving superplasticity at lower homologous temperatures (e.g., room temperature for aluminium and magnesium alloys) is enhancement of grain-boundary diffusion by engineering the grain-boundary composition and segregation through high-pressure torsion (HPT) process. This talk reviews some of the main attempts conducted for realizing the transition from low-temperature superplasticity to room-temperature superplasticity.

#00128

Irradiation and corrosion resistance of a nanostructured 316 austenitic stainless steel

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As it has been already shown in literature, reduction of grain size down to several tens or hundreds of nanometers leads to the enhancement of radiation resistance of metals [1-4]. Based on this approach, the aim of the Labex EMC3 (Energy Materials and Clean Combustion Center) project “Naninox” is to (1) establish links between the microstructure, the corrosion resistance and the hardness of a nanostructured stainless steel and (2) study the stability of the microstructure under ion irradiation ; thanks to this better irradiation resistance, a better corrosion resistance and higher mechanical properties after irradiation are expected in the ultra-fine grained stainless steel.
Ultra-fine grained 316L austenitic stainless steel samples have been produced by high pressure torsion (HPT) at 430˚C and then ion irradiated in Jannus facilities (CEA Saclay) at 450°C and 5 displacements per atoms.
Before and after irradiation, the microstructure has been described by using atom probe tomography and transmission electron microscopy. Corrosion behavior in NaCl solution was tested and nano-indentation tests were performed. All results obtained on the ultra-fine grained 316 austenitic steel are compared to those obtained on the classical 316 austenitic steel in order to discuss advantages of the grain refinement.

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Invited #0030

Low temperature superplasticity in ultrafine grained AZ31 alloy

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The mechanical behavior of an AZ31 magnesium alloy processed by high-pressure torsion (HPT) is evaluated by tensile testing from room temperature up to 473 K at strain rates between 10^{-5} – 10^{-2} s^{-1}. Samples tested at room temperature and at high strain rates at 373 K failed without any plastic deformation. However, significant ductility, with elongations larger than 200%, is observed at 423 K and 473 K and at low strain rates at 373 K. The high elongations are attributed to a pronounced strain hardening and a high strain rate sensitivity. The results agree with reports for a similar alloy processed by severe plastic deformation. However, the level of flow stress is lower, the strain rate sensitivity and the elongations are larger than the observed in this alloy processed by conventional thermo-mechanical processing.

#0037

Superplastic and diffusional bonding properties of Ti2AlNb based intermetallic alloy

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Abstract: With higher Nb element addition, the Ti3Al based intermetallic alloy have a significant improvement on mechanical and anti-oxidation properties, and it became a very attractive structure material for fabricating lightweight parts of aero engine or high-speed aircraft. The major combined phases of Ti2AlNb based intermetallic alloy (O phase alloy) are O phase, B2/beta phase and few of alpha2 phase which is more complicated compared with normal Ti3Al based alloy, i.e. Ti-24A-11Nb or super α2 alloy. The superplasticity of O phase alloy is much lower than α2 based alloys, but one of the application of O phase alloy sheet is forming hollow structure by SPF/DB processing. This paper is focused on the superplastic and diffusional bonding properties of Ti-23Al-27Nb alloy, aim at how to use it’s limited superplasticity to form a hollow structure and evaluating the properties of the hollow structure. On the other hand, dissimilar materials diffusion bonding at lower temperature and lower pressure were studied.

Keynote #0077

Study on the enhanced superplasticity of Mg-Li based alloy by a stepped deformation method

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A two-step deformation approach is proposed for the superplastic deformation (SPD) of Mg-9Li-1Al (LA91) alloy. This method has been successfully applied to titanium alloys and has induced enhanced superplasticity, and the feasibility of the method for the Mg-Li based alloy is explored. In a previous research, single-step SPD of LA91 alloy has been investigated, and the highest elongation of 563.7% was obtained by using the 8-pass equal channel angular extruded material, by the maximum strain rate sensitivity (Max*m*) mode deformation. While in this research, the raw material in the as-extruded state is utilized. Constant velocity (Constv) and constant strain rate (CSR) modes are adopted for the first step of the deformation, respectively, with the elongation of the first step from 50% to 150%. The Max*m* mode, in which the strain rate sensitivity *m* is always kept to be the maximum value, is applied to the second step. In addition, single-step tests by Constv, CSR and Max*m* modes until fracture are conducted. The experimental temperature is 300°C, which was proved to be the optimum temperature for the SPD of this material in the previous research. The result shows that the 2-step method can greatly improve the superplasticity of the LA91 alloy, especially for the CSR mode deformation, and the maximum elongation obtained is 535.3%, by the CSR-Max*m* mode, which is comparable to the optimum result in the previous research.

#00137

Formability analysis on Superplastic Forming of Magnesium alloy sheet

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Superplastic sheet metal forming allows the production of complex parts that are not formable under normal conditions. Superplastic sheet metal forming processes are normally based on the same common principle: the sheet metal is firmly clamped between the die halves and is blow-formed by means of gas pressure. Generally superplastic forming can only be achieved in a very narrow range of strain rates and temperature. Superplastic materials are relatively stable when deformed; this behavior is related to the observation that the flow stress of a superplastic material is very sensitive to the rate of deformation. This paper aims to study the formability characteristic of Magnesium alloy by considering variable parameters, such as the sheet thickness, forming pressure and forming temperature. The forming time of 120 minutes is constant for all samples.

#0029

Low-temperature superplasticity of the Ni-based EK61 superalloy and application of this effect to obtain sound solid state joints

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Ni-based superalloys are hard to deform and have low plasticity. For developing a technology for the parts processing the application of the superplasticity (SP) is promising. The traditional SP of Ni-based superalloys is associated with a high temperature (more than 950 °C). High processing temperature is a significant limiting factor for technology. The investigated EK61 alloy is the Russian analog of the well-known Inconel 718 superalloy by chemical and phase composition. The strengthening phase for both alloys is the gamma double prime-phase (Ni_3Nb). Authors revealed a low-temperature SP in the nickel EK61 alloy with a preliminarily prepared ultrafine-grained structure having an average grain sizes less than 1 μm. The maximum SP is displayed at temperatures of 800 and 850 ˚C, wherein the elongation was 1400 and 1200%, respectively. It has been experimentally confirmed that the use of low-temperature SP is a promising for obtaining a sound solid state joints by pressure welding of dissimilar Ni-based superalloys with a different type of strengthening phases. The investigations results of solid state joining of Ni-based superalloys EK61 and EP975 as well as Ni_3Al-based intermetallics have been defended by Patent 2608118 RU and can be commercially applied for manufacturing bimetallic parts used aircraft engines.

#00154

Thermal stability of UFG martensitic steels produced by severe plastic deformation

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High chromium ferrite-martensitic steel is considered a potential structural material for advanced nuclear reactors. To improve the efficiency, the operating temperature of these steels is expected to be raised to 600°C. It is known, that the creation of a UFG structure in such steels significantly increases the radiation resistance [1,2], however, thermal stability of the UFG structure has not been studied. In these studies, the UFG Grade 91 (9Cr–1Mo) martensitic steel and EI-961Sh (similar to 12Cr-2W-C) has been processed by high pressure torsion (HPT).
Structural features of the UFG samples (the average grain size, volume fraction and distribution of the martensite phases, size and phase composition of disperse precipitations) have been evaluated by the methods of electron microscopy and X-ray diffraction.
For the study of thermal stability, the samples have been annealed in the temperature range 400-700°C for 1 hour. For the Grade 91 steel the enhanced microhardness was stable up to 600°C. In the case of martensitic steel EI961Sh, when the samples were heated up to 450-500°C, the microhardness was increased by 15-20% to 8000 MPa, which can be explained by the release of dispersed carbide particles upon heating. In general, high values of microhardness remained after heating to a temperature of 600°C.
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#0041

Finite element modeling of manufacturing the spherical vessels by means of superplastic forming technique

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The comparison of two ways to manufacture spherical vessels by means of superplastic forming techniques is fulfilled in the present report. Firstly, conventional scheme of deforming a sheet into a cylindrical die is considered taking into account the influence of entry radius. Secondly, free forming of edge welded envelope consisting of two circular sheets welded along their circular periphery is also considered. The boundary value problem in the mechanics of solids is stated in terms of theory of creep while finite element solutions are obtained using ANSYS software. The comparison of the thickness distribution at the domes obtained is made. Besides the stress-strain state and the duration of forming is also compared. It is shown that the total time of forming for the case of free forming is approximately two times less as compared with conventional scheme while the thickness at the pole is greater.

#00131

Effect of ECAP prior to aging on microstructure, precipitation behaviour and mechanical properties of an Al-Cu-Mn-Mg alloy

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Microstructure, precipitation behaviour and mechanical properties of an Al-5.64Cu-0.33Mn-0.23Mg-0.14Zr-0.11Ti (in wt. %) alloy subjected to thermomechanical processing (TMP) involving equal-channel angular pressing (ECAP) to total strains (ε) of ~1 and ~2 followed by aging at 180°C for 0-28 h have been investigated and compared with conventional aging at the same temperature (T6). Intermediate ECAP followed by aging leads to significant increase in yield stress (YS) and ultimate tensile strength (UTS) and decrease in elongation-to-fracture as compared to peak-aged state of the T6 condition. The YS, UTS and δ values attained after ECAP to $\varepsilon \sim 2$ followed by peak ageing were ~510 MPa, ~540 MPa and ~7.6%, respectively. The changes in mechanical properties were related to microstructure evolution and precipitation behaviour, which were characterised using scanning and transmission electron microscopies. TMP conditions to obtain the high-strength Al-Cu-Mn-Mg alloy are discussed.

Invited #00162

Basic Concept and Seven Characteristic Features of Severe Plastic Deformation.

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In our work we have analyzed a great body of experimental data about structure formation in the metallic materials upon severe plastic deformation (SPD). We can define the following seven processes and phenomena typical exclusively of the SPD [1]:

∗ Fragmentation and formation of high-angle grain boundaries.
∗ Absence of strain hardening .
∗ Dynamical recrystallization.
∗ High diffusion mobility of atoms.
∗ Non-equilibrium and equilibrium phase transformations.
∗ Amorphization.
∗ Cyclic character of structural and phase transformations.

Within the basic concept of the emergence of additional channels of dissipation of mechanical energy supplied to the solid state, a general approach to the description of the basic laws of structural and phase transformations during severe SPD was proposed. It is shown that the active involvement of cyclic processes of low-temperature dynamic recrystallization and phase transitions of the "crystal ⇔ amorphous state" in conjunction with the appearance of additional thermal effects in low efficiency of dislocation and disclination accommodative processes capable of consistently explain almost all the main experimental results obtained to date during SPD [1].

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#0083

Studies on Ti54M Titanium Alloy for Application within the Aerospace Industry

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Since the development of Ti54M titanium alloy in 2003, its application within the aerospace sector has gradually increased due to the combination of a number of properties such as improved forgeability and machinability, superplastic characteristics, and low flow stress at elevated temperatures. However, for the successful exploitation of Ti54M, a comprehensive understanding of its mechanical characteristics, superplastic properties, and microstructure stability is required. Both forming temperature and strain rate during deformation influence these properties.

The superplastic forming of titanium alloys is characterised by high deformation at slow strain rates and high temperatures which influence the material microstructure, and, in turn, determine its forming behaviour. This mechanism challenges the ability to predict the material behaviour, limiting its application within the aerospace industry.

Even though Ti54M has been commercially available for over 10 years, further studies of its superplastic properties are therefore required with the aim of assessing its applicability within the aerospace industry as a replacement of other commercial materials (e.g. Ti-6AL-4V).

In this work a study of the mechanical and superplastic properties of Ti54M, in comparison with other commercial materials (e.g. Ti-6AL-4V) used in the aerospace industry, are presented. The results of this work will also be used to calibrate and validate a material model developed within the Advanced Forming Research Centre (University of Strathclyde, UK) that is able to estimate the superplastic behaviour and grain size evolution of the material.

#00122

Influence of high-pressure torsion on structure amorphous melt-spun Ti-Ni-Cu alloys

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The TEM studies in the cross section (on lamella) of HPT-processed sample of the melt-spun (MS) amorphous $Ti_{50}Ni_{25}Cu_{25}$ alloy were conducted. The initial MS ribbons have a typical amorphous structure. Areas in the HPT sample with different structures were observed. The first area is shear bands with nanocrystallization inside. The second area is areas with a cluster-type amorphous structure around shear bands. In the STEM HAADF mode, dark clusters with a size of 25 nm, divided by bright boundaries, are recorded. According to the previous studies, in some cases nanocrystallization was observed [1], in others cases the formation of a cluster-type amorphous structure was observed [2] in the MS $Ti_{50}Ni_{25}Cu_{25}$ alloy after HPT. Shear bands are not revealed in the course of planar TEM studies of the HPT-processed sample [1], but are clearly visible in the lamella in the cross section of sample. Density measurements according to the new procedure [4] demonstrate that HPT leads to a decrease in the values of density (increase in the free volume) of MS alloy.

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#00104

Simulation and experiment investigation on superplastic forming/ diffusion bonding process of a Ti-6Al-4V alloy rear fuselage part

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Superplastic forming/ diffusion bonding (SPF/ DB) process is widely used in aviation titanium alloy parts forming. PAM-STAMP was utilized to simulate the superplastic forming process of Ti-6Al-4V double layer superplastic/ diffusion bonding rear fuselage part under 920℃ and reach the thickness distribution of the part. Then the designed part was formed based on simulation. The thickness distribution of the practical part was measured and compared with the simulation result. The results show that the thickness distributions of practical and simulated part fit well with each other and the thinning of the practical part is severer than the simulated one.

#00114

Mechanical behavior of twinning induced plasticity steel processed by warm forging and annealing

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The present study investigates the microstructure evolution and mechanical properties in Twinning Induced Plasticity (TWIP) steel processed by warm forging and/or subsequent annealing. The results show that the as-forged and 750^0C-annealed samples exhibited an apparent yield-point phenomenon and very high yield strength while the high temperature, 850^0C, annealed samples did not. The initial density of dislocations not only determined whether the yielding point phenomenon appeared or not, but affected the evolution of dislocations during the subsequent tensile deformation. Original high dense dislocations in the as-forged and low temperature annealed samples prompted the rapid increase of dislocations, and intensified the complexity of dislocation configurations. All these effects made the twinning deformation weakened but the dislocation deformation enhanced, leading to increased strength but decreased plasticity.

Keynote #00136

Superplasticity: past, present and future

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This paper summarizes some of the findings in very fine-grained superplastic metallic materials in recent 30 years. Attention is paid to high-strain-rate superplasticity with positive strain rate exponent in aluminum-based materials, low-temperature superplasticity in magnesium-based materials, and room-temperature superplasticity in Zn-Al alloys, which have been attained by the improvement of grain size refinement processing. Engineering applications of these technologies will also be introduced. For future advancement in the field of superplasticity, it is important to understand grain boundary plasticity, which is termed as the plastic flow caused by grain boundary sliding, from the knowledge of structure and atomic bounding of grain boundaries. This presentation concludes with some guesses about future directions for the field.

#0052

Superplastic Zirconia-Magnesia-Spinel Composite Fabricated by a Two-Step Sintering Method

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In order to fabricate a new magnesia-based superplastic composite, a two-step sintering method was applied to the CIP-ed compacts of a mixture of magnesia, tetragonal zirconia and alumina powders. After two-step sintering in air to a relative density of 99%, the sintered body exhibited a tri-phase structure consisting of 40 vol% magnesia, 30 vol% alumina-magnesia spinel and 30 vol % tetragonal zirconia and the zirconia grains were dispersed uniformly among the grains of the former phases. Microstructural examination showed that the spinel phase occurred by chemical reaction during the first step of heating. The present material with an average grain size of 600 nm exhibited superplasticity at a medium strain-rate region around 10^{-3} s^{-1} and at 1375-1450 °C. Under this condition, tensile properties of the material were similar to those of an Al_2O_3-Spinel-ZrO_2(3Y) composite material. The present study also addressed failure behavior during superplastic tensile deformation.

Invited #00120

Ultrafine Grain Refinement for Superplastic Forming Using Incremental Feeding Technique in HPT and HPS

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Severe plastic deformation (SPD) produces ultrafine-grained structures in many metallic materials so that superplasticy may appear when deformed at elevated temperatures. In particular, SPD under high pressure is of great interest because grain refinement is attained even in hard-to-deform materials. High-pressure torsion (HPT) [1] and high-pressure sliding (HPS) [2] are typical SPD processes under high pressure, where the former uses disks or rings and the later sheets or rods. Nevertheless, a major requirement is to up-scale the sample size for practical application. This presentation demonstrates that the incorporation of successive sample feeding in the HPT and HPS processes can upsize the SPD-processed area without increasing the machine capacity. This combined process, called incremental feeding HPT (IF-HPT) [3] and incremental feeding HPS (IF-HPS) [4], is applied to a Ni-based superalloy (Inconel 718) well known as a heat resistance material with excellent corrosion resistance. It is shown that elongation more than 400% is achieved in a high-strain rate regime ($>1x10^{-2}$ s^{-1}). It is also demonstrated that cup forming of the Inconel 718 with practical dimensions is realized by taking advantage of the superplasticiy through grain refinement by the IF-HPT and IF-HPS processes.

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#005

Effect of different initial lamellar plate thickness on the grain refinement and superplastic behaviour in HPT-processed Ti-6Al-4V alloy

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Ti-6Al-4V alloy was heated to above β phase transformation temperature with two different cooling speeds: air cooling (AC) and furnace cooling (FC), in order to generate a full fine lamellar structure and a full coarse lamellar structure, respectively. Then the alloy in two heat treated conditions was processed at room temperature up to 10 turns by high-pressure torsion (HPT) processing. Investigations were carried out to study the effect of the different initial lamellar plate thickness on microstructure development and grain refinement during HPT processing, and the corresponding superplastic behaviour at selected low testing temperatures of 873 and 923 K.

#0040

Calculation of the initial profile of a preform for superplastic forming of hemispheres of uniform thickness

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The problem to calculate the initial profile of a circular disk to obtain hemisphere of a pre-given uniform thickness by means of standard superplastic forming of sheet into a cylindrical die is considered. Analytical procedures enabling one to calculate the initial thickness distribution in the original disk to be deformed is developed. Finite element modeling of the process under consideration is fulfilled using ANSYS software. Boundary value problem in the mechanics of soliuds is stated in terms of theory of creep, superplastic properties being found from the results of technological experiments. Special attention is given to the influence of the entry radius on the deformation of a sheet. It is shown that insufficient value of the entry radius of the die used may lead to the localization of the deformation in the vicinity of the entry radius when forming original disks having considerable thickness at central zone as compared with periphery. At the same time, if the value of the entry radius of the die used is sufficient one can obtain hemispheres of uniform thickness.

#00149

Grain Growth-Driven Superplastic Deformation of Fine-Grained 5083 Aluminum Alloys

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Methods to synthesize laboratory-scale fine-grained materials by severe plastic deformation (SPD) have recently evolved. In this study, friction stir processing (FSP) of the 5083 aluminum alloy was performed to introduce a fine-grained microstructure having an average grain size of 7.4 ± 0.2 μm. To investigate their thermal stability, the FSP samples were static annealed. It was confirmed that at temperatures above 673 K the FSP samples exhibited rapid grain growth. High-temperature tensile tests of the FSP samples were conducted across wide ranges of the initial strain rate and temperature. Large elongations (>200%) were obtained for the FSP samples despite their tendency for grain growth. The strain rate sensitivity exponent (*m*) was estimated as 0.5 from the true stress-true strain rate relationship corresponding to a strain of 10%, and indicated grain boundary sliding. Crystal grains elongated in the tensile direction were observed for strains of over 100%. This deformed microstructure greatly resembled the microstructure of the superplastic-like 5083 Al−Mg based alloy "Class I solid solution". The superplastic-like behavior has been reported as the transgranular deformation of individual crystal grains through solute drag creep. Therefore, it was thought that solute drag creep contributed to the large elongations observed during the later stages of deformation. In this paper, the abovementioned phenomena will be discussed in detail from the viewpoints of high-temperature deformation mechanism and microstructural observations.

#00182

Steady-state flow in some heavily deformed metals

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Plastic flow behavior in heavily deformed aluminum and tungsten was investigated. Aluminum specimens containing 0.1 to 1.0 mass % Fe and 0.3 mass% Si were cold-rolled from 2.5mm to 0.04mm in thickenss. Tungsten sheet specimens with 2 mm thickness were prepared by sintering, hot-rolling. Aluminum foils were tensile-tested at room temperature and at different strain rate. Tungsten specimens were tensile-tested at at strain rates ranging from 1.4×10^{-3} s^{-1} and 1.4×10^{-1} s^{-1} and at temperatures ranging from 300 to 600°C. Testing temperatures of the two metals are far below $T_M/2$ where T_M is the absolute melting tempeatre in Kelvin unit. Steady-state flow was observed in both metals. The mechanism for this flow was discussed based on dynamic recovery or dinamic recrystallization. The effect of Fe content and annealing was also invetigated in aluminum.

#0059

Improvement of superplastic properties in SPZ by small addition of Sn

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Superplastic deformation is known to be a stress during tensile deformation of the polycrystalline material which exhibits a high strain rate dependency, and a phenomenon showing the large elongation of several hundred percent or more without causing necking.
In present study, superplastic behavior of a Zn 22 mass % Al eutectoid alloy (SPZ) with small addition of Sn (SPZSn) was investigated. Granular grain size of about 0.3 μm was obtained by water quench after annealing SPZ and SPZ05Sn (addition of 0.05 mass % Sn into the SPZ) at 653 K for 2 h. Microstructure observation by Scanning Transmission Electron Microscope (STEM) showed additive Sn was present at the α' grain boundary in the SPZ05Sn. Excellent high strain rate superplasticity was achieved in the SPZ05Sn, with elongation of more than 1300 % at 523 K at strain rate of 10^{-1} S^{-1}. The large elongation and high strain rate sensitivity value of the SPZ05Sn tend to shift to higher strain rate region as compared to those of the SPZ. It was considered that the small addition of Sn into the SPZ effectively suppressed the grain growth of α and β phases during the superplastic deformation, because granular grains less than 2 μm is maintained after superplastic deformation at 523 K. Stretch formability of SPZ05Sn was improved at 473 K at high strain rate, and there were no in-plane anisotropy and failure direction.

#00167

Thermal stability of commercially pure Ti and Ti-6Al-7Nb alloy processed by ECAP

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Microstructure evolution and thermal stability of ultra-fine grained (UFG) commercially pure (CP) Ti and Ti-6Al-7Nb processed by equal-channel angular pressing (ECAP) were investigated. Recovery and recrystallization processes both in the coarse grained and UFG material were characterized by in-situ electrical resistance variations. Thermal stability of the UFG structure was investigated by scanning electron microscopy and X-ray diffraction and correlated with microhardness measurements. Recovery processes in CP Ti and Ti-6Al-7Nb were found to occur in similar temperature ranges and both materials are stable up to 440°C. Microstructure changes occurring during severe plastic deformation of both materials are discussed in detail.

#00108

On the Effect of the Complexity of the Constitutive Model in Simulating Superplastic Forming

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Accurate constitutive material models are essential for the realistic simulation of metal forming processes. However, for superplastic forming (SPF), mostly the material models found in literature are based on the fitting of the simple power law equation. In this study an investigation was carried out on the effect of the complexity of the constitutive model on the accuracy of the SPF simulation results. This was achieved by following an experimental-numerical investigation of the SPF of the AZ31B magnesium alloy. At first, high temperature bulge forming tests and microstructural analyses were carried out to generate the data required to fit two different constitutive models. The first is the simple power law. The second model takes into account grain growth and cavity formation in addition to the strain and strain rate hardening. Secondly, simulations of SPF of parts with different complexities were carried out and the results were compared with those obtained from actual forming experiments. Results show that both models are capable of predicting the thickness distribution and the shape of the formed part to a good degree. However, the more complicated model shows a better capability in predicting the forming time.

#0076

Influence of Heat Treatment on Microstructure and Properties of Titanium Alloy after SPF/DB

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Influence of solution and aging treatment parameters on microstructure and mechanical properties of TC4 titanium alloy after SPF/DB was investigated through microstructure observation and mechanical properties test .The results show that microstructure of TC4 titanium alloy after heat treatment consists of primary α phase and fine acicular α+β phase. With increasing solution temperature，primary α phase content decreases，while yield strength and tensile strength decreases then increases. With increasing aging temperature，grain size of acicular α+β phase gradually increases， while tensile strength gradually decreases and plasticity increases.

#008

The effects of Mn and Fe on the superplasticity of high-Mg aluminum alloys

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Aluminum alloy AA5083, Al-4.7%Mg-0.7%Mn, has been used as inexpensive superplastic forming (SPF) material, but its chemical composition, especially the Mn and Fe levels, was initially optimized for cold forming. In the present work, the high temperature formability of modified AA5083 with 0.5-1.5 wt.% Mn and 0.05-0.27 wt.% Fe was evaluated by tensile testing at 425-525°C with strain rates from 2×10^{-4} to 2×10^{-2} s^{-1}. The effects of Mn and Fe on the intermetallic phase, grain structure and cavitation were systematically investigated. It has been found that Mn refines and stabilizes the grain structure by particle stimulated nucleation (PSN) and Zener pinning, respectively. Although Fe has grain refinement effect by PSN as well, it drastically reduces the superplasticity by facilitating the forming of pre-existent cavities during the sheet processing, and the nucleation, growth and inter-linkage of cavities upon SPF.

#00176

Grain growth and superplastic deformation of aluminum alloys

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The role of grain growth in aluminium alloys containing nanoscale dispersoids during static annealing and superplastic deformation in attaining ductility is considered. Discontinuous grain coarsening under static conditions suppresses superplasticity. High superplastic ductility could be attaining if continuous grain coarsening takes place in grip section of tensile specimens under superplastic conditions. Low rate of static grain growth is provided by Zener drag force and is a prerequisite condition for attaining superior superplastic performance. In gauge length of tensile specimen the strain-induced grain growth occurs that leads to decreasing the coefficient of strain rate sensitivity with strain and promotes strain-induced cavitation. As a result, instability of plastic flow and/or premature pseudo-brittle fracture attributed to the formation of coarse cavities with irregular shape take place. Dynamic grain growth increases superplastic flow stress and may provide significant contribution of strain hardening to stability of plastic flow. This type of structural superplasticity is observed at pre-melting temperature in Sc-free Al alloys. Features of this type of superplastic behavior are considered.

#00174

Structure and mechanical properties of ultrafine-grained high-Mn TWIP steel

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The influence of thermomechanical treatment consisting of cold rolling followed by annealing on the structure and mechanical properties of an Fe-18Mn-0.6C-1.5Al (wt. %) high-manganese TWIP steel was studied. The steel with initial thickness of 10 mm was deformed to 8, 6, 4 and 2 mm, which corresponds to 20, 40, 60 and 80% rolling reduction. The rolled samples were subsequently annealed within the temperature range of 400-700°C for 30 minutes. The cold rolling resulted in a significant increase in yield strength from 295 MPa to 1520 MPa, while annealing of the steel specimens deformed with 20-80% reduction for 30 minutes at 400°C did not lead to any noticeable decrease in strength. The recovery processes took place at a temperature of 500°C. Annealing at temperatures of 600°C and 700°C led to the formation of a partial and completely recrystallized structure, respectively. The recrystallization processes led to a drastic decrease in strength and an increase in ductility. The yield stress after annealing at 700°C was 435 MPa, the tensile strength was 940 MPa with an elongation of 64%, respectively. The average size of the recrystallized grain was ranged from 1 to 8 μm, depending on the conditions of rolling and annealing.

#00170

Influence of a multi-axial isothermal forging on the structure and properties bearing steel at elevated temperatures

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Carbide heterogeneity is a disadvantage of bearing steels. During operation, bearings experience variable loads, as a result in crumbling of carbides and bearing is destructed. Elimination of the carbide phase separation of the cast structure is carried out by metal pressure treatment methods. However, traditional methods of processing, such as rolling or pressing, eliminating the segregation of the cast structure, lead to the formation of a different kind of heterogeneity - carbide banding, while the carbide phase remains heterogeneous.
In this paper, the feasibility of using a multi-axial isothermal forging (MIF) method to eliminate carbide inhomogeneity and enhance the mechanical properties of Fe-0.8C-4Cr-9W-2V steel has been investigated. The deformation was carried out at a temperature of 500 °C for 4 passes in three directions of applying the load. The total degree of deformation was e = 1.6.
It is shown that, as a result of MIF, the ultrafine-grained microstructure of the ferrite matrix with uniformly distributed highly disperse carbide particles is formed. An increase in strength characteristics was observed both at room temperature and at temperatures of 250-450 °C after multi-axial isothermal forging compared with the initial state of steel. This is due both to the grain-boundary hardening of the ultrafine-grained ferritic matrix and to the formation of complex special carbides up to 100 nm in size.

#0022

Friction Stir Butt Joints of Dissimilar AA6061-T6 & AA7075-T651 Aluminum Alloys: Study of Grain Refinement and Tensile Behavior of Weldment

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Butt joining of dissimilar AA6061-T6 and AA7075-T651 aluminum alloys which are very difficult to weld without any defects by utilizing the traditional fusion welding processes were joined using Friction Stir Welding, a solid-state joining technique. The mechanism of grain refinement process for the development of fine microstructure in the weld nugget zone during friction stir welding of dissimilar alloys is an interesting features for the researchers. Variations in the welding process parameters such as tool feed rate ,tool rotational speed , tool pin geometry ,axial force etc., play a vital role in the grain refinement process in the weld nugget zone which in turn gives impacts on the tensile, fatigue, wear and corrosion behavior of the welded joint. In this analysis, a tri-vex tool with the tool rotational speed of 800 rpm, 900 rpm and 1000 rpm, the tool traverse speed of 45 mm/min, 60 mm/min and 75 mm/min and the axial force of 12 kN were incorporated to study the impacts on the grain refinement process and the tensile properties. The experimental results show the formation of very fine grains in the stir zone in the order of 5-8 µm due to the dynamic recrystallization (DRX) with the tool rotational speed of 900 rpm and tool traverse speed of 60 mm/min condition and hence superior microstructural and tensile properties were enhanced in the butt joints of welded materials.

Keynote #0010

Superplastic Flow and Micro-Mechanical Response of Ultrafine-Grained Materials

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Bulk ultrafine-grained (UFG) materials usually show superior mechanical and physical properties. Since the occurrence of superplastic flow generally requires a grain size smaller than ~10 µm, it is reasonable to anticipate that materials processed by severe plastic deformation (SPD) will exhibit superplastic ductilities when pulled in tension at elevated temperatures. Recent advances in the processing of UFG metals have provided an opportunity to extend the understanding of superplastic flow behavior to include UFG materials with submicrometer grain sizes. Moreover, very recent studies showed the UFG materials demonstrated the development of micro-mechanical response at room temperature by the significant changes in microstructure attributed to HPT. Accordingly, this presentation reviews recent results that demonstrate the occurrence of exceptional superplastic flow in a series of UFG alloys after equal-channel angular pressing (ECAP) and high-pressure torsion (HPT). The results are analysed to describe the superplastic flow behavior by the theoretical mechanism developed for micrometer-grained metals so that flow in UFG materials may be interpreted using conventional flow mechanisms. Moreover, this presentation summarizes the evolution of small-scale mechanical response examined by the nanoindentation technique on various UFG materials processed by HPT. Special emphasis is placed on demonstrating the evolution of the micro-mechanical behavior in these UFG materials by estimating the strain rate sensitivity.

#00148

Effect of structure on the strength and fatigue of an Al-Cu-Mg alloy

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The dependence of strength and fatigue on microstructure of the Al-Cu-Mg alloy has been investigated. Various microstructures of the alloy were produced: the first sample with a coarse-grained (CG) structure after T6 heat treatment; the second one with a homogeneous ultrafine-grained (UFG) structure and the third one with a bimodal (mixed) structure, both processed by equal-channel angular pressing (ECAP). The mean grain size and morphology of precipitates were studied by transmission electron microscopy. The ultimate tensile strength and the fatigue endurance limit were determined using the tensile and fatigue tests of standard specimens. It is established that the formation of a homogeneous UFG structure and of a bimodal (mixed) structure alloy contributes to a significant increase in microhardness by 16% and 60%, and an increase of the ultimate tensile strength by 20 and 52%, respectively, as compared to the samples subjected to T6 heat treatment. Fatigue tests show that the alloy with a bimodal (mixed) structure has the highest fatigue endurance limit, 45% higher than in the sample subjected to T6 heat treatment. In contrast, the formation of a homogeneous UFG structure enables increasing the fatigue endurance limit by 15% only.

#00166

High-pressure omega-phase creation and its thermal stability in nanostructured Ti–based alloys

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To develop multifunctionality of the Ti-based alloys, the creation of promising nanostructured states is one of the key directions. Severe plastic deformation by high-pressure torsion (HPT) permits to obtain substantial refinement of the microstructure and extremely high density of the defects, including enormous vacancy concentration. It assumes an important reason for the investigation of phase transformations induced by HPT as well as upon subsequent heating.
In the present study, nanostructured (α+β) Ti alloys containing β-stabilizing elements such as Fe, Co, Cr were performed by HPT technique. HPT-induced α- and β- to ω-phase transitions were revealed in dependence on doping element content, applied pressure and shear strain by means of X-ray diffraction, transmission electron microscopy and differential scanning calorimetry. The transformation kinetics was compared with the kinetics of pressure-induced transition. Orientation relationship between α-, β- and ω-phases were taken in consideration and analyzed according to theoretical calculation proposed earlier. The influence of initial state before HPT appeared to be considerable for the ω-phase formation. Thermal stability of the HPT-induced ω-phase was studied and discussed as well in frame of mechanical behavior of Ti and Ti-based alloys produced by shear deformation under high applied pressure.

#0028

Role of Grain-Boundary Sliding on Sintering

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A grain-boundary sliding model is constructed to investigate the densification characteristics in the intermediate stage of sintering under compressive hydrostatic pressure. The sintering behaviour was analysed with a mechanism of grain-boundary sliding accommodated by grain-boundary diffusion for a dense matrix polycrystal containing spherical pores. For sufficiently large pores, the present discrete model approaches the continuum model, whereas for small pores, grain-boundary sliding is restricted to occur and the present model deviates significantly from the continuum model. When the pore size is smaller than 3 times the grain size, the densification rate decreases rapidly. For sufficiently small pores, the pore shrinkage by grain-boundary sliding is limited. Then, further shrinkage occurs by grain-boundary diffusion only, where the final-stage sintering begins. The critical pore size for the mechanism transition is predicted taking into account the results of the final-stage model. The validity of the present model is verified by comparing the densification rate with the experimental observations during sintering of ceramic powder.

Invited #00169

Single-roll angular-rolling for continuous severe plastic deformation process

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In this presentation, we present a new continuous severe plastic deformation (SPD) process for metal sheets developed recently, named single-roll angular-rolling (SRAR). The SRAR process achieves maximized deformation homogeneity of metal sheets by combining circumferential shear deformation with channel-angular shear deformation. The grain refinement and mechanical properties were investigated experimentally in relation to the number of repetitive SRAR passes. The finite element method was used to demonstrate that the SRAR process provides highly uniform SPD by strengthening the less deformed region that inevitably occurs near the lower part of the workpiece during the channel-angular deformation processes.

#00105

The effect of annealing on the microstructure and mechanical properties of the cold-rolled CoCrFeNiMn high entropy alloy

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The effect of annealing on the microstructure and mechanical properties of the cold-rolled equiatomic CoCrFeNiMn high entropy alloy (HEA) was studied. The CoCrFeNiMn alloy was prepared by vacuum arc melting, homogenized at 1000°C for 24 hour, and rolled at room temperature to 80% of the thickness strain. The rolled alloy was used as a starting material. The deformed CoCrFeNiMn alloy was annealed at temperatures of 600-900°C for 1 hour. The structure of the HEA was studied using X-ray diffraction analysis, scanning and transmission electron microscopy. The cold-rolled alloy is characterized by single face-centered cubic solid solution and heavily deformed twinned/subgrained structure. After annealing at ≥700°C fully recrystallized structure with numerous annealing twins is observed. The recrystallized grain size increases from ~1.3 µm after annealing at 600°C to ~17 µm at 900°C. The formation of second Cr-rich phases was observed after annealing at 600-800°C. The cold-rolled condition of the alloy demonstrates high ultimate tensile strength of 1175 MPa but a negligible strain hardening capacity results in poor ductility: the uniform elongation is 1.5%. Good combination of strength and ductility can be obtained after annealing. The CoCrFeNiMn high entropy alloy becomes softer and more ductile with increase of annealing temperature, for example, after annealing at 900°C yield strength decreases to 630 MPa, and uniform elongation increases to 45%. The contribution of the precipitation strengthening to the overall strength of the annealed alloy was evaluated.

#004

Orientation dependence of twinning in FCC single crystals of high-entropy alloys

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The deformation hardening at tensile strain of the FCC CoCrFeMnNi (I), CoCrFeMn (II), and $CoCrFeNiAl_{0.3}$ (III) high-entropy alloys (HEA) were studied in a wide temperature range of 77-573 K. It was shown that in single crystals of I, II alloys, with a value of stacking fault (SF) energy 0.02 J/m^2, the twinning deformation starts in $[\bar{1}11]$-crystals after 5% strain, in $[\bar{1}23]$ after 27% and in [001] it was not detected. At 77K, the twinning in $[\bar{1}11]$-, $[\bar{1}23]$-crystals shifts to the beginning of plastic strain. For the first time, twinning was observed in [001]-crystals of (I) HEA in tensile strain at 77K. The development of twinning simultaneously with slip leads to an increase in the strain hardening coefficient as compared to slip. Deformation twinning was realized in $[\bar{1}11]$-crystals by nucleation and growth of an intrinsic SF and in [001]-crystals by the extrinsic SF. A nucleation mechanism of twins by intrinsic and extrinsic SFs was proposed. An increase in the SF energy up to 0.05 J/m^2 in (III) HEA crystals suppresses twinning at 296 K and it occurs in $[\bar{1}11]$- and [011]-crystals only at T=77 K after the previous slip deformation of 15-20%.

#0042

On superplasticity of aluminium alloys

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Generalization of the mechanical experiments results on the establishment of thermomechanical conditions for transition of industrial aluminum alloys to a superplastic state is presented. The effect of so-called "dynamic superplasticity" is considered as superposition of the coherent deformation rates and structural-phase transitions of evolutionary type in the open nonequilibrium systems. It is proposed an approach applying to the modelling of the superplastic flow of commercial aluminum alloys taking into account the boundary regions in the framework the theory of self-organization of dissipative structures. As this takes place, the equation of state written in the final form and supplemented with evolutional equations for the control parameter and the internal parameters of the state. In industrial processes of three-dimensional type the effect of superplasticity is rational to use in the form of the mentioned dynamic approach, when instead of the preliminary preparation of fine grain structure to realize the superplasticity effect the objective is the manufacture of the final semi-finished product under superplasticity conditions with fine-grained structure. The methodology of mathematical modelling of three-dimensional type forming processes implemented in the form of the solution of two related tasks: isothermal boundary-value task the solution of which establishes the power and kinematic parameters of the process of deformation in the temperature range of not beyond the limits of the thermal range of superplasticity and the problem of optimizing building functions controlling the formation process is developed.

#00135

Effect of isothermal multiaxial forging on microstructure and mechanical properties of Ti/TiB metal-matrix composite

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Mechanical behavior and microstructure evolution of Ti/TiB and Ti-15Mo/TiB metal-matrix composites during multiaxial forging (MAF) at 700 and 800°C and a strain rate 10^{-3} s^{-1} were studied. The composites were produced using spark plasma sintering at 1000°C. Mechanical behavior in terms of aggregated σ-$\Sigma\varepsilon$ curves during the MAF at both temperatures demonstrated a pronounced softening following by a steady-like flow stage. Microstructure evolution during the MAF at both temperatures was associated with dynamic recrystallization and the formation of dislocation-free areas of ~1 μm in diameter and areas with high density of TiB whiskers and high dislocation density. The length of TiB whiskers considerably decreased after the first step of the multiaxial forging and then changed insignificantly. The MAF of the Ti/TiB and Ti-15Mo/TiB composites at 700 and 850°C to cumulative strain ~5.2 resulted in a considerable increase in low-temperature ductility without substantial loss in strength. For instance, a Ti/TiB metal-matrix composite after MAF at 700°C demonstrates elongation of 14% during a tensile test at 400°C whereas elongation of only 0.5% was obtained in the as-sintered condition at the same temperature.

#0038

Tensile properties of AZX612 alloy sheets processed by Friction Assisted Extrusion

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Tensile properties at room and elevated temperatures of the AZX 612 (Mg-6%Al-1%Zn-2%Ca) alloy sheets processed by a kind of lateral extrusion method namely Friction Assisted Extrusion (FAE) were investigated. The FAE was developed to control the texture, and carried out at temperatures ranging from 250 to 350˚C with an extrusion ratio of 4:1 from the as-rolled condition. The results showed that FAE changes the basal texture of the as-rolled material into that inclined by about 15˚ toward the extrusion direction and raises the intensity of the texture. The microstructure was presumed to be refined by dynamic recrystallization by FAE. The 0.2% proof stress of the material at room temperature became significantly smaller than that of the as-rolled material in the extrusion direction but became larger in the transvers direction, resulting in the larger anisotropy. This can be understood by the activity of basal slip. On the other hand, the anisotropy of the tensile properties disappeared at a temperature of 300˚C and a strain rate of $3.3\times10^{-4}s^{-1}$. In addition, the elongation was improved from 72% of the as-rolled material to 152% at maximum of the FAEed material in the extrusion direction. This improvement in ductility cannot be explained only by the increase in the activity of non-basal slip systems but also by other deformation mechanism such as superplastic flow.

#0043

Strees Behavior of a Circular Membrane under Superplastic Forming Conditions

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Superplastic forming of a circular membrane is the most intensively studied mode of superplastic deformation. As a rule, main attention is paid to the stable stage of this process. In this report, main attention is given to the analysis of stress evolution from the very beginning of the deformation process and up to the formation of hemisphere. With this in view, the elastic strain is taken into account in analyzing the stress evolution during the process. Simplified mathematical model is developed withion framework of the main assumptions of the thin shell theory. Analytical expressions for calculating the values of maximum stress (at the initial peak) and minimum stress are derived along with corresponding expressions for estimating the dome height. To validate the approach suggested the boundary value problem in the mechanics of solids is stated in terms of the theory of creep. Finite element solutions are obtained using ANSYS software. It is shown that the approach suggested enables one to estimate reliably the characteristics values of the stress, maximum deviation does not exceed 7% with respect to the values of stress and 5 % with respect to the dome height.

#0014

Investigation of grain boundary ensemble of the copper M1 subjected to equal-channel angular pressing after annealing

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The grain structure of the copper M1 subjected to equal-channel angular pressing and followed annealing at 593K for 1 hour was investigated by scanning electron microscopy using diffraction of backscattered electrons and transmission electron microscopy. It was established, that annealing promotes the formation of an inhomogeneous grain structure in submicrocrystalline copper. The increase in grain size and the formation of special boundaries, predominantly twins Σ3, both low- and high-energy are observed. The migration of the high-energy twins Σ3 and grain boundaries of general type, the splitting of the special boundaries Σ9 to the twins Σ3 and grain boundaries of general type to the special boundaries Σ9 and Σ3 are observed. It was found that the grain boundaries of general type transform to special boundaries in the local places. The particles of the Cu_2O phase are present on the migrating twins Σ3 and grain boundaries of general type.

#0044

Determination of Superplastic Properties from the Results of Bulge Forming of Rectangular Sheets

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The procedure to determine the strain rate sensitivity index, m, of a superplastic material from the results of constant pressure forming of rectangular sheets is suggested. Unlike of other known approaches the method suggested is taken into consideration the influence of entry radius of the die used. The analytical model of the process under consideration is developed within framework of the thin shell theory while the boundary value problem in the mechanics of solids is stated in terms of the theory of creep. Finite element solutions of the boundary value problem stated is found by means of standard ANSYS software. The validity of the results obtained are confirmed by comparing the finite element solutions with corresponding experimental data recorded on titanium sheet alloy Ti-6Al-4V, a good agreement being found. It is shown that the procedure suggested enable one to determine reliably the value of strain rate sensitivity index, m, which depends no on the value of entry radius. The procedure suggested appears to be more pertinent when finite element modeling of 3-sheet structures as compared with standard approaches based on the usage of constant pressure forming of circular sheets.

#0025

The strength and ductility of low carbon steel subjected to equal channel angular pressing and extrusion at a low temperature

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Deformation processing of low-carbon steel Fe360 by extrusion, equal channel angular pressing, and equal-channel angular pressing with extrusion in a single pass at a temperature of 673 K are considered. Increasing the strength of the steel in all methods of treatment is shown. The characteristics of the conditional strain diagram of the material under uniaxial tension in various states at room and low temperature is analyzed. The difference between the characteristics of steel ductility, depending on the type of treatment and test temperature is observed.

#00109

Effect of solid solution composition on superplastic behavior of Al–Zn–Mg based alloys

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Grain refinement methods of wrought Al-based AA7000 type alloys mostly based on either formation of fine particles/dispersoids (Sc, Zr, Cr) or severe plastic deformation techniques. The composition of the alloys (in terms of Zn, Mg and Cu) mainly corresponds to the commercial alloys, which have high strength properties. However, the effect of the solid solution alloying degree with the above mentioned elements on the grain size and superplastic behavior is clarified poorly.
This work was aimed on detail study of the Zn and Mg effect on the microstructure evolution and superplastic deformation behavior of the Al–Zn–Mg–type alloys alloyed by eutectic and dispersoids formed particles and exhibited unrecrystallized grain structure before start of the superplastic deformation. It was found that fine grain structure and high strain rate superplasticity can be achieved due to (1) a bimodal size distribution of particles and (2) the presence of highly alloyed solid solution. Dynamic recrystallization was inhibited at heating and beginning of deformation in low alloyed materials, which was cause of poor superplasticity. An increase of the Zn and Mg amount in the aluminum solid solution at superplastic deformation temperature stimulates formation of finer grains, low flow stress, high strain rate sensitivity index *m*, and high elongation. Finally, alloys exhibit ability to superplastic deformation in a strain rate range of 10^{-2} to 10^{-1} s^{-1} with elongation up to 1000%.
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#0075

Modified procedure to determine superplastic properties from the results of technological experiments

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Novel procedure to determine the values of material constants K and m for standard power superplastic law Backofen from the results of bulge tests of hemispheres is suggested. Unlike of other approaches known in the literature the procedure involved requires only two experimental measurements of time of forming under constant pressure, the thickness at the pole being used to refine the values K and m. Experimental approbation of the techniques developed is fulfilled on the example of commercial titanium alloy Ti-6Al-4V. The validity of the approach suggested is confirmed by comparing the experimental data with corresponding finite element solutions of the boundary value problem in the theory of creep obtaining by using ANSYS 10ED software. It is found that the maximum deviation of the experimental records from the corresponding finite element solutions does not exceed 5% as for the time of forming as well as for the thickness at the pole.

#00107

The strength and ductility of low carbon steel subjected to equal channel angular pressing and extrusion at a low temperature

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Deformation processing of low-carbon steel Fe360 by extrusion, equal channel angular pressing, and equal-channel angular pressing with extrusion in a single pass at a temperature of 673 K are considered. Increasing the strength of the steel in all methods of treatment is shown. The characteristics of the conditional strain diagram of the material under uniaxial tension in various states at room and low temperature is analyzed. The difference between the characteristics of steel ductility, depending on the type of treatment and test temperature is observed.

#00102

Microstructure of an Al-Mg-Sc-Zr alloy after FSW and ECAP processing schemes

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The Al-5.4Mg-0.2Sc-0.1Zr alloy with initial coarse grained (~90 µm) microstructure and dispersed coherent nanoscale Al_3(Sc,Zr) particles with an average size of ~9 nm was subjected to equal channel angular pressing (ECAP) at temperatures ranging from 300 to 450°C up to a total strain of ~12 or to friction stir welding (FSW) with the rotation speed ranging from 350 to 800 rpm for 1 and 2 passes. In the latter case, the opposing sides were treated avoiding kissing bond defects and the temperature increase (up to 550°C) during straining was carefully measured. The strain-induced microstructure evolution is compared for the two different processing routes. Both techniques are found to produce a uniform microstructure with an average grain size ranging from ~ 0.9 to ~2.9 µm. The use of two passes of FSW led to grain coarsening. The ECAP processing produces finer grains with a significantly higher dislocation density as compared to FSW. This fact is explained by a higher resistance of the Al_3(Sc,Zr) dispersoids to coarsening during ECAP with respect to that under FSW. Continuous dynamic recrystallization is assumed to govern the grain refinement in both processing routes. Higher processing temperatures and a decreased Zener drag force due to larger Al_3(Sc,Zr) particles result in enhanced grain coarsening under the FSW conditions.

#0094

Computer simulation of the superplastic forming of 3-sheets structure containing ultrafine-grained core

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Superplastic forming of three sheets structure containing nanostructured core and two microcrystalline face sheets is considered both analytically and by means of finite element consideration. Analytical approach is based on the thin shell theory. Standard power law of superplasticity is used. Optimal pressure-time cycle is calculated both for the case of constant strain rate forming as well as for constant stress forming. Ti-6Al-4V 3-sheet structure is considered as an example of application for the procedure suggested. The approach suggested is verified by using ANSYS software, a good agreement of the analytical predictions with corresponding finite element solutions is found.

#00133

The structure and mechanical properties of Mg-Zn-Ca alloy processed by equal channel angular pressing

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It is known that magnesium is completely biocompatible and can be used as a material for manufacturing biodegradable implants. At the same time pure magnesium has insufficient strength to be used in medicine. In metallic materials the mechanical properties can be improved by grain refinement using severe plastic deformation. In the present work the structure of the magnesium alloy Mg-1%Zn-0.2%Ca after equal-channel angular pressing (ECAP) has been studied by optical, scanning and transmission electron microscopy. It was established that increasing the equivalent strain by increase a number of passes through a ECAP die leads to more pronounced grain refinement in the alloy. When equivalent strain achieved 7.2, an average grain size of 2 μm was observed. It was shown that the ECAP samples enable to demonstrate the microhardness of 69.5 HV and the enhanced ultimate tensile strength of 282 MPa, which is more than 2 times higher in comparison with the homogenized state, while maintaining ductility.

#00177

On primary recrystallization of high-Mn austenitic steels

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The grain refinement is an effective approach to strengthen high-Mn TWIP/TRIP steels. The development of recrystallized microstructure with a grain size of about one micron increases the yield strength of high-Mn steels above 500 MPa. The fine grained microstructures can be easily developed by cold rolling followed by primary recrystallization. The recrystallized grain size can be expressed by a power law function of the strain hardening during the previous cold rolling with an exponent of -2. Taking the dislocation density as the main strengthener, the grain size is an inverse proportion to the dislocation density. Then, the number density of recrystallized grains can be expressed by a power law function of dislocation density evolved during cold rolling with an exponent of about 2.

#00178

On atomistic modelling of twin boundaries in magnesium

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Magnesium and its alloys are prospective low weight materials. Deformation of such materials are often accompanied by deformation twinning due to significant plastic anisotropy of hcp structure. Atomistic modelling is popular instrument for study of twinning mechanisms. There is variety of interatomic potentials, which are commonly used for modelling. However, structure and properties of twin boundaries can vary in the models based on different potentials. In the present study, we provide comparison of twin boundary properties predicted by several embedded atom method interatomic potentials for magnesium.

#0095

Analysis of the evolution of mechanical properties metallic materials by AMD-methods for thermomechanical impacts

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One of the topical material science problems today is the problem of analyzing the evolution of the mechanical properties of metallic materials, predicting their behavior under thermomechanical influences. To solve this problem, it is suggested to use methods of acoustomicrous flaw detection or AMD-methods. They make it possible to obtain, with the aid of acoustic waves (AB), images of the structure at various depths from the surface of the object. This does not require any additional surface treatment, including chemical etching. The advantages of analyzing the evolution of the mechanical properties of alloys using AMD methods are related to the fact that acoustic waves and their characteristics are sensitive both to the parameters of the structural elements and to their changes associated with external influences.
Under the influence of the applied stresses the structure of the object is constantly changing, which means that its properties also change. At the same time, depending on the temperature conditions, humidity and test time, the rate of transformation of the structure and properties of materials changes. AMD-methods allow one to evaluate the change in the physical and mechanical characteristics of metallic materials, observe the nucleation of defects in them, determine the areas of critical stresses and local destruction. In materials obtained by powder technology, the forecasting of the behavior of the material was carried out both from an analysis of the porosity level from acoustic images, and from the values of the velocity of acoustic waves and the level of their absorption.

Invited #0021

Thirty Years of Superplastic Ultrafine-Grained Materials: Examining the Legacy of Oscar Kaibyshev

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The occurrence of superplasticity may be traced to the classic work of Pearson conducted in the U.K. in 1934 when an elongation of 1950% was reported in a Pb-Sn eutectic alloy. Subsequently, much attention in Russia was devoted to this scientific curiosity and this led to the first book on superplasticity written by Prof. A.A. Presnyakov and published in 1964. Later, in 1985, Oscar Kaibyshev established in Ufa the Institute of Superplasticity Problems of the Russian Academy of Sciences and this was, and remains to this day, the only institute in the world devoted exclusively to studies of the phenomenon of superplastic flow. An important development occurred in 1988 with the publication of a classic report by Kaibyshev and co-workers describing the potential for achieving low temperature superplasticity in a metallic Al-Cu-Zr alloy that had been specially processed by severe plastic deformation (SPD) to produce a remarkably small grain size of only 300 nm. This report formed the basis for the later development of SPD processing as a major tool for the production of exceptional grain refinement and as a procedure for achieving exceptional superplastic elongations that cannot be achieved using more conventional processing. This paper describes this early work, the subsequent developments and the modern status of superplastic flow in ultrafine-grained metals.

#00145

Unified anisotropic model of creep-plasticity interaction for large strain applications

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Forming of structural elements from structural alloys is considered in combined regimes of creep and superplasticity. This approach has an advantage over traditional methods of plastic deformation due to reduced forming forces and saving the material’s strength. In order to control the shape and strength of the workpiece, an accurate mathematical simulation of the forming process is needed. It requires unified material models accounting for creep damage, ductile damage, large strains and inelastic anisotropy.

The study presents a comparison of two creep models with a scalar damage parameter in application to non-stationary torsion of circular tubes and bending of rectangular beams under large strain conditions. Consideration of large strain kinematics in the first model (Shutov et al.) is carried out in a geometrically exact way due to the multiplicative split of the deformation gradient tensor. The first model also includes backstresses to account for anisotropy. The second model (Sosnin) does not take the backstresses into account. Data of tests on deformation of cylindrical samples, bending of beams and results of model validation are given.

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#0034

Superplastic deformation behavior of as-received and hydrogenated Ti_2AlNb alloy

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In this paper, effect of temperature and initial strain rate on the superplasticity of as-received Ti_2AlNb alloy was studied by uniaxial tensile tests. Temperature from 870℃ to 1030℃ with an interval of 40℃ and initial strain rate range of 6×10^{-4}~$6\times10^{-2}s^{-1}$ were selected. The optimal superplasticity of 190.3% was obtained at 990℃ with initial strain rate of $3\times10^{-3}s^{-1}$. The superplastic properties were deteriorated at 1030℃ due to serious grain coarsening. In order to improve superplastic properties, as-received alloy was hydrogenated with different hydrogen contents. It was found that hydrogen addition can significantly decrease flow stress and increase elongation. A higher elongation occurs at 910℃ in hydrogenated alloy.

#0078

Simulation and experiment investigation on superplastic forming/ diffusion bonding process of a Ti-6Al-4V alloy rear fuselage part

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Superplastic forming/ diffusion bonding (SPF/ DB) process is widely used in aviation titanium alloy parts forming. PAM-STAMP was utilized to simulate the superplastic forming process of Ti-6Al-4V double layer superplastic/ diffusion bonding rear fuselage part under 920℃ and reach the thickness distribution of the part. Then the designed part was formed based on simulation. The thickness distribution of the practical part was measured and compared with the simulation result. The results show that the thickness distributions of practical and simulated part fit well with each other and the thinning of the practical part is severer than the simulated one.

#0048

Investigation on Austenite Transformation Kinetic Mechanism of Ultra-high Strength Steel by Rapid Heating

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Rapid heating can refine the austenite grain and shorten the austenitizing time of ultra-high strength steel. And it can also improve the balance of strength and ductility of hot stamping parts. In the process of rapid heating, due to the large degree of superheating, the process of austenite transformation of ultra-high strength steel is different from the isothermal transformation process, and its mechanism needs to be further studied. In the paper, based on the principle of variable-speed transformation kinetics, the austenite transformation kinetic model of rapid heating is explored. Then, the Gleeble-3500 thermal simulation testing machine is used to conduct the rapid heating experiment. The kinetic parameters of extended kinetic model are obtained by thermal expansion experiment at different heating rates. Finally, the extended kinetic model of austenite transformation of rapid heating is gotten. The results shown that the volume fraction of austenite solved by the extended kinetic model was in good agreement with the experimental data at different heating rates. The model can well reflect the actual austenite phase transformation of ultra-high strength steel.

#00189

Fabrication of Nanocomposite Magnets via Severe Plastic Deformation

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Nanostructured exchange-coupled nanocomposite permanent magnets are considered as the next generation of high strength magnets for future applications in energy-saving and renewable energy technologies. However, fabrication of bulk nanostructured magnets remains very challenging because conventional compaction and sintering techniques cannot be used for nanostructured bulk materials processing. In this talk I will review recent efforts in producing bulk nanostructured single-phase and composite magnetic materials with emphasis in severe plastic deformation methods (based on “the noodle mechanism”) that have led to formation of the hard/soft exchange coupled nanocomposite magnets including the SmCo/FeCo systems with homogenous soft magnetic phase distribution in nanoscale in the matrix of the hard magnetic phases. Up to 300% energy density enhancement has been achieved in the isotropic bulk nanocomposite magnets.

#0012

Bulk metallic glasses as ideally formable materials on heating yet retaining their ultrahigh strength upon further cooling

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The reasons for excellent formability of metallic glasses on heating will be described in this presentation. Metallic glassy alloys and their composites have a low viscosity in the supercooled liquid region and flow under pressure. They show non-Newtonian flow near the glass-transition temperature (T_g) and then Newtonian flow in the supercooled liquid region having viscosity of 10^6-10^{10} Pa·s yet retaining their high strength after subsequent cooling [1,2]. The boundaries of these temperature regions (inhomogeneous deformation by localized shear bands at moderate temperature, non-Newtonian and Newtonian homogeneous flow) are strain rate dependent [1,3].
Thus, various glassy alloys exhibit “superplasticity” (good fluidity) on heating up to the supercooled liquid region and can be thermo-mechanically shaped or welded [4]. Micro-gears with complex geometries and various micro- and nano-scale patterns can be produced [5]. Bonding of glassy alloys can be achieved by Joule heating, laser, electron-beam and friction welding [1,2]. As structural relaxation on annealing below T_g significantly influences plasticity/toughness of metallic glasses this process should be avoided by rapid heating above and subsequent cooling below T_g.
Glassy composite alloys such as $Cu_{55}Zr_{30}Ti_{10}Co_5$ [6] can be deformed in the semi-solid state up to 850 K at low load (the viscosity is < 10^{10} Pa·s) owing to the equiaxed morphology of the nanoscale crystalline phase. This procedure can be applied to certain families of other metallic glasses which exhibit a multistage crystallization behavior, thus producing crystal/glassy samples of complex shape.

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#0053

Effect of hydrogen on structure and mechanical properties of high-nitrogen austenitic steel processed by high-pressure torsion

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The microstructure and microhardness of ultrafine-grained high-nitrogen Fe-19Cr-21Mn-1.3V-0.8N-0.3C (in wt.%) steel were investigated before and after electrochemical hydrogen charging of the specimens. The ultrafine-grained state in the steel were produced by cold high-pressure torsion (HPT, 20°C, p= 6 GPa, for one revolution). Hydrogen saturation was performed in 3% NaCl water solution containing 3 g l^{-1} of NH_4SCN as recombination poison at current density of 10 mA/cm^2 for 15 hours. Examination of X-rays diffraction data indicates that hydrogenation of HPT-processed steel specimens leads to a broadening of X-rays peaks and their shifting as result of stacking-faults formation and residual stresses. Hydrogenation of HPT-processed steel promotes to gamma-epsilon martensitic transformation, which was proved both by X-rays diffraction and electron microscopy. Due to hydrogen-induced phase hardening, the microhardness of the steel increases from 6.5 GPa in hydrogen-free state to 6.8 GPa in hydrogen-charged one.
This research was supported by the Russian President Scholarship (SP 160.2016.1).

#0047

Characterisation of Mechanical Properties and Formability of a Superplastic Al-Mg alloy

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In order to develop a reliable constitutive model for predicting formability and springback of sheet metals during superplastic forming (SPF) and quick plastic forming (QPF), characterization of elastic-plastic behaviour as well as formability of the material is essential. In the present study, the module of elasticity, uniaxial flow behaviour and anisotropy, as well as the forming limit curve (FLC) of one of a SPF/QPF grade AA5083 was investigated. The variation of Young's modulus with temperature was measured from the uniaxial tensile tests for four temperatures ranging from 25 to 470 ºC. The impact of temperature and strain rate on the flow behaviour of the material was investigated via uniaxial tensile tests for three temperatures (450, 470, and 490 ºC) and at three strain rates (0.001, 0.01, and 0.1 s^{-1}). The dependency of the flow stress on the material orientation with respect to the rolling direction (0, 45, and 90º) was assessed using uniaxial tensile tests at a constant temperature. In addition, the evolution of plastic anisotropy with plastic strain and strain rate was assessed by measuring the Lankford coefficient (r-value). Finally, the FLC of the material at 470 ºC was characterized according to Nakazima tests procedure for three strain paths (i.e. uniaxial tension, plane strain, and biaxial tension).

#00110

Influence of vanadium-alloying on microstructure, phase composition and microhardness of high-nitrogen austenitic steel under high-pressure torsion

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The influence of high-pressure torsion on microstructure and microhardness of high-nitrogen steels Fe-23Cr-19Mn-0.5N-0.2C (I) and Fe-18Cr-23Mn-2.5V-0.8N-0.3C (II), wt.% was investigated. Initial specimens were water-quenched after 1200 °C, 1 h. After quenching the steels have predominantly austenitic structure (steel I) with carbonitrides of Cr and V (steel II). The concentration of (C+N) in solid solution after quenching was near the same in both steels (~0.7 wt.%). The steels were processed by high-pressure torsion (HPT, 20°C, p= 6 GPa, N=0 (upset), 1/4, 1/2 and 1 turn). Electron microscopy observation shows that after HPT for N=1 structure of steel I presented by twin net. The structure of steel II was combined and presented by two characteristic regions: by twin net and misoriented structure with both low- and high-angle boundaries. The presence of fine precipitates (Cr,V)(N, C) with the size of 5 nm was indicated in steel II after HPT for N=1, they were homogeneously distributed in steel structure. High-pressure torsion is accompanied by a significant increase in the microhardness of the steels from 300 HV (steel I) and ~ 400 HV (steel II) in the initial states up to 600 HV (steel I) and 610 HV (steel II) after torsion for one full revolution.
This research was supported by the RFBR (18-48-703023 r_mol_a).

#00117

Investigation of the Complexities Inherent in Manufacturing Near-Unconstrained Superplastic Parts by Experiments and Simulation

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Superplastic forming is a sheet metal forming process that has found widespread use in the aerospace industry. It produces parts that are free of residual stresses, dimensionally accurate, and with strains unobtainable using conventional methods. When combined with diffusion bonding, a phenomena where under similar processing conditions the material involved will produce a near flawless weld with itself, a variety of reinforcements and internal structures can be produced. In most superplastic parts the material is blow formed up to a die and the material takes on the dimensions of the die. In this work, however, we investigate a process unique to superplastic forming with diffusion bonding using four sheets. The two outer sheets are formed up to the die while the two inner sheets form a complex sandwich structure. Superplasticity is stress-history dependent and somewhat chaotic in nature. Therefore the inner sheets have a large variance in geometry due to the fact that they have only limited constraints and are free to shift and translate as the forming operation progresses. The variances in forming are quantified using a variety of techniques to measure the major features of the process including cell wall measurements, gas pathway measurements, and computer vision based geometry analysis. We use three dimensional finite element simulations of the inner sheet forming process to compare the characterization results with idealized geometry. The results of the analysis provide insights into the complexities of manufacturing such internal structures as well as the chaotic nature of the superplasticity itself.

#0015

Increase of the elasticity and strength of the welded joints for the Al-Mg-Li alloy made by the laser welding by means of the thermal-mechanical processing

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The paper deals with the analysis of the effect of the thermal mechanical processing on the mechanical characteristics (elasticity and tensile strength) of the welded joints of the aluminum alloy, the system Al-Mg-Li. The microstructures of the basic alloy and welded joint before and after the thermal processing are compared by electronic microscoping. The X-ray diffraction method is used to compare the phase composition. The variations are shown in the microstructure and phase composition in the welded joint as compared with the basic alloy. The welded joint structure is dendritic. The concentration of the strengthening phase δ'(Al_3Li) reduces in the welded joint, which results in the low mechanical characteristics. The thermal processing, namely quenching, increases the concentration of the equilibrium S_1 phase (Al_2MgLi) in the welded joint as compared with an unquenched joint. The elasticity of the welded joint rises significantly at the almost constant strength, the value of the relative extension lies within the range of 2.4 – 19.2 % before and after quenching, respectively. Artificial ageing applied to the welded joint after the quenching gives the structurization of the S_1 phase and partial extraction of the phase δ'. The welded joint strength rises, the elasticity decreases. It is shown that the elastic deformation (deformation degree 10%) applied to the welded joint results in the increased strength of the joint. The full thermal mechanical processing (quenching, elastic deformation, artificial ageing) of the welded joint of the aluminum alloy (the system AL-Mg-Li) results in the tensile strength increase up to 0.95 of the basic alloy strength.
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#0065

Enhanced mechanical properties, corrosion resistance and fatigue strength of magnesium alloy WE43 after multiaxial deformation

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In this work, the effect of multiaxial deformation (MAD) on the structure, texture, mechanical properties, corrosion resistance and fatigue behaviour of the bioresorbable magnesium alloy WE43 was studied. The deformation of the alloy was carried out with a stepwise decrease of temperature from the initial 450 °C to 300 °C at the final pass with successive drops in temperature of 25 °C. The total number of deformation passes for each temperature was four. The deformation led to increasing strength and ductility of the alloy due to the formation of ultrafine-grained (UFG) structure with an average grain size of ~1 μm. The yield strength and the ultimate tensile strength rose to 210 MPa and 300 MPa, respectively, in comparison with 150 MPa and 220 MPa in the initial state. The tensile elongation increased from 10.5% in the initial state to 17.2% after deformation. The formation of the UFG structure also resulted in improvement of the resistance to chemical corrosion in a 0.9%NaCl solution. The corrosion rate decreased from 0.93±0.20 mg/cm^2*day in the initial state to 0.56±0.05 mg/cm^2*day after MAD treatment, while the resistance to electrochemical corrosion was not sensitive to the treatment. High-cycle fatigue tests, which were carried out under repeated tension, showed a positive effect of UFG structure formation on fatigue life of WE43 alloy. MAD treatment was found to lift the fatigue limit of WE43 alloy from 90 MPa in the initial state to 160 MPa after processing.
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#00118

Molecular Dynamics Investigation of Titanium Grain Boundary Sliding Resistance and Its Effect on Crystallographic Texture Evolution during Superplasticity

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Superplastic forming is a sheet metal forming process that has become a widespread technology for producing parts in the aerospace industry. It provides the advantages of producing parts that are free residual stress and are capable of high dimensional accuracy even with shapes that would be unformable with conventional methods. The mechanisms in superplasticity are predominantly grain boundary sliding with two different accommodation mechanisms that prevent voids forming in the process: dislocation based Rachinger sliding and diffusion based Lifshitz sliding. This study presents a simulation of superplastic forming that is rate limited by grain boundary sliding using computed resistances that are based on the crystal orientation and using Lifshitz sliding as the accommodation mechanism. The grain boundary sliding resistance between a spectrum of grain orientations of titanium are computed using molecular dynamics. The resistances are mapped onto randomized crystal structures. The combination is then used in a superplastic flow simulation using rigid body phase field methods to see any changes in flow based on texture. This technique gives qualitative insight into the effect of the initial crystal texture on superplastic properties caused by a variety of manufacturing processes.

#0051

Dynamic anisotropic grain growth during superplasticity in quasi-single phase aluminium alloys

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The microstructural features of dynamic anisotropic grain growth were characterized during superplasticity in a quasi-single phase Al–Mg–Mn and Al–Zn–Mg alloys. The tensile superplasticity was predominantly mediated by grain boundary sliding (GBS) that was accommodated by grain rotation and only a limited crystallographic slip. The deformed sample showed a bimodal microstructure; some grains have maintained their initial size and equi-axed morphology during superplasticity, while the others have become elongated more than twice in their aspect ratio and they were sub-divided into equi-axed sub-grains aligned along the tensile axis. These microstructural features were possibly attributed to a rotation-coupled grain coalescence accompanied by GBS. This elementary process of dynamic anisotropic grain growth was directly observed by 3D tomography of electron back-scattered diffraction combined with an internal marker technique.

#00156

The development and the industrial application of the Infra-Red heating for the superplastic forming

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The superplastic forming (SPF) is used in aeronautics in order to manufacture titanium parts with complex shapes. Comparing to others forming processes, the SPF needs more time and therefore is more expensive. Indeed the forming is realized under an isothermal environment with a massive metallic tool. Thanks to its experience in SPF parts production, in process simulations and in tools manufacturing, Aurock aimed at improving the SPF process efficiency and developed a new heating solution to save manufacturing costs. Using Infra-Red lamps to heat directly the blank is an economic way to raise the temperature as the heating time is cut to a few minutes instead of 24 hours. Nevertheless, this technology involves rethinking the process and considering an anisothermal environment. The tool core is not completely heated anymore, leading to greater efficiencies.

Radiative flux model was developed and complex thermomechanical simulations have been used as a predicting tool of the infra-red lamps power. The lamps power is adjusted throughout the forming step in order to obtain an optimized flux by the development of a numerical PID controller. This optimisation of lamp power ensures a homogeneous temperature of the blank during the superplastic forming. Through these simulations, several TA6V sheets with a size of 500x500 mm^2 were firstly and successfully formed by using this technology. The blank microstructure is not affected by the quick heating phase. Secondly, standard aircraft parts with a size of 1 m^2 were likewise formed which demonstrates the efficiency of the IR heating for the industrial superplastic forming.

#00192

Enhancing effect of solution treatment on electrical and mechanical properties of Al-4.5(Ce+La) alloy after high-pressure torsion and subsequent annealing

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This paper reports on a study of the crucial role of solution treatment before plastic deformation on enhancement of electrical and mechanical properties. Cast Al-4.5(Ce+La) alloy samples processed with and without solution treatment were subjected to high pressure torsion at room temperature followed by annealing at 280°C for 1 hour. The optimal combination of strength and conductivity without solution treatment was obtained for 280°C annealing temperature, while application of solution treatment resulted in outstanding combination of higher conductivity and only slightly lower strength at significantly reduced annealing temperature of 230°C.

#0097

Effect of composition on superplastic deformation mechanisms of aluminium based alloys

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The study of superplastic deformation mechanisms at different strain-temperature-stress conditions would provide a better understanding of superplasticity phenomena and would help researchers to develop novel materials with better superplasticity. Three follows mechanisms are typically associated with superplastic flow: grain-boundary sliding (GBS), dislocation slip/creep and diffusion creep. Despite a well-developed phenomenological description, so far a complete scientific understanding of the fundamental deformation mechanism to ensure superplasticity has been limited.
In a current study evolution of the deformation behavior, surface and bulk structures at superplastic flow of various aluminum based alloys were analyzed by scanning and transmission electron microscopes and a focused ion beam (FIB) technique. Several Al-Mg (AA5083 type) and Al-Zn-Mg (AA7475 type) based alloys, which have recrystallized and unrecrystallized grain structure before start the superplastic deformation were used for comparison. The evolution of the GBS contribution at deformation according to the analysis of the offsets of FIB-milled grids was studied. It was found that Mg rich alloys of Al-Mg based system exhibit significantly lower contribution of GBS in a total strain as compare to Al-Zn-Mg based alloys. The differences between deformation behavior and contributions of GBS at a primary stage and a steady stage were evaluated. Grain neighbor switching, grain rotation, dispersoid free zones and insignificant intragranular strain were observed in various alloys at both stages. The role of dislocation and diffusion creep mechanisms in superplastic deformation was discussed. The current results highlight the importance of diffusion creep as well as grain boundary sliding mechanism for various aluminum based alloys.
The work was supported by the RSF Grant# № 17-79-20426.

#0016

Superplasticity of friction-stir welds of Zr-modified 5083 aluminum alloys with ultrafine-grained structure

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The commercial Zr-modified 5083 aluminum alloy was homogenized to precipitate nano-scale Al_6Mn particles and then undergone to equal-channel angular pressing (ECAP) at 300°C to a true strain of ~12 via B_C route. The obtained ultrafine-grained material was subjected to friction-stir welding (FSW). The welding variables were selected to provide reasonable homogeneous microstructure distribution across the weld zone and thus to ensure a highly uniform elongation during subsequent superplastic tests of the joints. Superplastic behavior of the obtained welds is discussed.
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#00116

Novel Al-Mg-Si based superplastic alloy

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The aluminum alloys of Al-Mg-Si type are widely used in aircraft and mechanical engineering due to high mechanical and corrosion properties as well as low cost and density. Moreover, such alloys exhibit the possibility to form the supersaturated solid solution at air cooling with subsequent significant aging effect. Unnecessary of rapid water cooling is very attractive for superplastically formed parts. However, superplasticity of Al-Mg-Si-based alloys is poorly studied. The most detailed investigation was carried out for AA6013 and AA6061 alloys by L.P. Troeger and E.A. Starke Jr. It was found that the superplastic effect with a maximum strain rate sensitivity of 0.5 and elongation of 375% can be achieved at a very low strain rate of $1 \cdot 10^{-4}$ c^{-1} which is not sufficient for industrial SPF.
The purpose of present study is to develop a high-strain-rate superplastic Al-Mg-Si based alloy with composite type structure. The influence of eutectic-forming elements on microstructure, mechanical properties and superplastic parameters was studied. The decomposition of Zr-supersatured solid solution and the formation of Al3Zr precipitation were particularly investigated using TEM microscopy and Vickers hardness method for various homogenization modes. The optimum homogenization regime was identified. The optimization of aging regime and the analysis of the corrosion properties were also performed. The cold rolled sheets expose the unrecrystallized structure before start of the superplastic deformation and provide the elongation to failure above 400% at strain rate of $1 \cdot 10^{-2}$ c^{-1} in a temperature range of 400-500 ºC.
The work was supported by the RSF Grant# № 17-79-20426.

#00193

Effect of strain on strain hardening of an Al-Mg alloy

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Mechanical behaviour of an Al-Mg alloy cold rolled with a reduction of 70% followed by recrystallization annealing at 400°C for 2 h was examined at room temperature and initial strain rates ranging from 10^{-3} s^{-1} to 5×10^{-3} s^{-1}.. The alloy having uniform structure with an average grain size of 40 μm exhibits Portevin-Le Chatelier (PLC) effect with B type serrations. Discontinuous yielding occurs immediately after the elastic limit. The alloy exhibited a short yielding plateau associated with the nucleation and fast propagation of a deformation band. At strain hardening stage following yielding plateau the nucleation and propagation of numerous PLC bands along specimen axis was found. Strain and strain rate strongly affect strain localization within PLC bands and local strain rate. Correlations between mechanical behaviour and characteristics of nucleation and propagation of PLC bands are considered.
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#0011

Influence of DC Current on the High Temperature Deformation of Zirconia Ceramics

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Flash sintering phenomena, which occur by imposing a high electric field directly to compacted powders, can succeed to lower the sintering temperature and to reduce the sintering time to less than a few seconds of several oxide ceramics. It is well known that the high electric field can also enhance the high temperature deformation of ceramics. The present study was performed to examine the effect of the high electric current on the high temperature deformation of polycrystalline 8Y-CZP (8mol% Y_2O_3 stabilized cubic ZrO_2).
For the fine grained 8Y-CZP with less than 1μm, the flash event similar to that of powder sintering occurs even in the bulk materials by imposing the electric current higher than a critical value E_c. The E_c value is 100-200 mW/mm^3 at around 1000 °C. For lower than E_c, the imposed current increases the sample temperature depending on the imposed power, but does not enhance the rate of deformation. For higher than E_c, the electric field can enhance the rate of the deformation to 10 times as compared with that of no current condition. The enhanced deformation cannot be explained only by the increment of sample temperature and is likely to occur by the flash event. The current, however, does not affect the stress exponent and activation energy. In the presentation, we will discuss the detailed current effect obtained at wide range testing conditions.

#00130

Effect of initial heat treatment on microstructure and properties of low-alloyed copper alloy subjected to ECAP-processing

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The microstructure evolution, mechanical and function properties of a low-alloyed copper alloy subjected to solution treatment (ST) at 1193 K for 1 h with water quenching or aging (AT) at 823 K for 4 h followed by equal channel angular pressing (ECAP) at a temperature of 273 K to total strains from 1 to 4 were examined. After the first ECAP pass, the development of a large number of strain-induced grains occurs within initial grains regardless of initial state. Upon further processing, the grains elongate along the metal flow direction and the significant grain refinement is observed. The large plastic straining results in significant strengthening. The ultimate tensile strength increases from 190 MPa to 440 MPa and from 215 MPa to 445 MPa in ST and AT samples, respectively, after total strain of 4. A modified Hall-Petch relationship is applied to evaluate the contribution of grain refinement and dislocation density to the overall strengthening. The effects of initial heat treatment and plastic deformation on electroconductivity are discussed in some detail.
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#0056

The ion-nitriding of surface layers in austenitic steel processed by cold rolling

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The grain-subgrain structure with a high concentration of deformation defects (boundaries/subboundaries, twins, dislocations, etc.) contributes to a more intensive diffusion of nitrogen and allows to further improve functional properties of austenitic steels during ion nitriding. This work is aimed at studying of the structural peculiarities and phase composition of surface layers of CrNiMnMo (AISI 316-type) austenitic stainless steel with a grain-subgrain structure subjected to low-temperature ion nitriding. Samples of austenitic steel after cold rolling at 300 K to an upset degree of 80% had a misoriented grain-subgrain structure and a high density of dislocations. After rolling, CrNiMnMo steel was ion nitrided for 12 hours at a temperature of 813 K and a working gas pressure P=300 Pa. TEM analysis shows that the nitrided layer has a complex structure: thin surface film (20 nm) composed of oxycarbonitrides is formed on the surface; a subsurface layer of 20-25 μm in thickness is observed, consisting of dispersed nitrides of 20-30 nm in size, nitrided ferrite and austenite. In the diffusion zone, with increasing distance from the surface of samples, the portion of nitrides gradually decreases, and the main phase is nitrogen-saturated austenite, which contains high density of deformation twins. The presence of a high density of deformation defects and grain boundaries in the initial structure after cold rolling of CrNiMnMo steel promoted its partial relaxation during nitriding with formation of deformation twins.

#00198

Friction stir processing trials of SP-700 (Ti-4.5Al-3V-2Fe-2Mo) titanium alloy

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Superplastic titanium alloy (SP-700 with nominal composition of Ti-4.5Al-3V-2Fe-2Mo) an alpha-beta alloy, with a beta-rich fine microstructure and excellent superplastic formability has wide applications in aerospace components, metal wood heads, tools, automotive components. However, very little information is available regarding friction stir processing (FSP) characteristics of this alloy. This study discusses the trials of FSP of this highly formable titanium alloy. Results are discussed in terms of hardness and temperature measurements and microstructural observations.

#00205

Microstructure and properties of the Al alloy, subjected to the high pressure torsion extrusion

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High Pressure Torsion Extrusion (HPTE) is a novel and the most promising in terms of industrial use process of severe plastic deformation (SPD), because in a combination with Conform™ technology it can be used for the manufacturing of long rod-shape billets with ultrafine grained structure. During HPTE, the specimen is extruded through sectional containers rotating relative to each other. The HPTE technique exploits the deformation mechanics of HPT in rod-shape samples and is capable of applying high strain to materials in one pass. During processing samples are exposed to a gradient of strain - similar to conventional HPT.
Samples of the commercial Al 6101 alloy with a typical chemical content, namely: 0.58 Mg; 0.54 Si; 0.23 Fe; 0.003 Cu; 0.01 Zn; 0.012 (ΣTi + V + Cr + Mn); res. Al (wt. %) after solid solution treatment were processed using HPTE technique with different regimes at 100°C. Some specimens after room temperature HPTE were artificially aged (AA) at temperatures of 130 and 170 °C.The microstructure, hardness, tensile properties and electrical conductivity of samples in as-processed state and after AA were analyzed. It has been established that HPTE-processing with accumulated strain of 1 leads to the formation of a gradient microstructure with ultrafine grained (UFG) structure with elongated grains with sizes in the range of 500-900 nm on the sample. As-processed samples revealed high ultimate tensile strength ≥320 MPa, and electric conductivity was in the range 29.2-30.3 MS/m (50.3-52.2% IACS respectively), depending on the processing regime. AA after HPTE resulted to the simultaneous increase both in the strength for ~10% and electrical conductivity up to 33.8 MS/m (58.2 % IACS). The influence of the HPTE regimes and subsequent AA on the microstructure and properties of the 6101 alloy are discussed.
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Invited #00187

Effect of solute on grain boundary plasticity in fine-grained Mg alloys

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Magnesium alloys are the lightest commercial alloys and have great potential for weight reduction of vehicles to save the natural resources and to reduce the CO_2 gas emission. It has been demonstrated that wrought processing, i.e., extrusion and/or rolling, effectively enhances the strength by means of refining grain structure in magnesium alloys. Besides the grain refinement, adding solute element plays an important role for the strengthening. The effect of solute has not been, however, fully understood yet to enhance the mechanical properties in the fine-grained magnesium alloys.
In this study, mechanical properties in binary alloy extrusions were examined by tension test in a wide range of strain rate, 10^{-4} s^{-1} ~ $4x10^3$ s^{-1}, to clarify the role of solute atoms, *e.g.*, yttrium and/or lithium for enhancing the strength. Deformation mechanism was investigated by estimating activation energy and stress exponent based on the data for tension tests. The results suggested that contribution of grain boundary sliding was minimized by the solute segregation and resulted in enhanced ductility under dynamic loading. On the other hand, three-point bending test was conducted at dynamic strain rate to investigate fracture behavior at dynamic strain rate. As a result of the impact three-point bending, it was suggested that yttrium solute enhanced the absorbed energy of magnesium, while lithium reduced. First principles calculations were conducted to understand the role of solute on enhancing the strength of grain boundary. Evaluated cohesive energies on grain boundaries suggested that segregation of yttrium solute effectively enhanced the strength of grain boundaries and resulted in the enhancing toughness.

#00144

Evaluation of wear resistance of copper at sliding under load against TiC based coatings

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The main problem in deformation treatment of copper products is its adherence on deforming tool. Adhesive wear affects the quality of the copper billet, worsening the surface, significantly reduces the service life of the deforming tool. One way to prevent adherence of copper on tools is using liquid lubricants. An alternative is to cover the contact surface of the deforming tool by wear-resistant anti-adhesive coatings.
The aim of the study is to evaluate frictional interaction between copper and wear-resistant coatings based on titanium carbide.
Flat samples made of Russian tool steel Kh12MF with the coatings were used for the study. They were obtained by electrospark deposition (ESD) using electrodes made of Russian steel alloy STIM-2/40NZh, and also the same alloy modified with tungsten nanoscale additives.
Tribological properties were measured on TRIBOMETER (CSM Instruments) using “pin-on-plate” reciprocating mode, corresponding to ASTM G 99-17. A copper counterbody was a rounded 6 mm rod. Quantitative evaluation of adherence and wear done by optical profilometer (WYKO NT 1100).
It was found, that two different types of interaction of the copper counterbody with coatings - with adherence and without it. Uncoated tool steel contained copper islands on track, while TiC-based coatings were without any traces of copper. Thus, the experimental tribological study showed that least (0.07) coefficient of friction shown by ESD coating made of electrode material with nanoscale tungsten additives. So, TiC based coatings are perspective to secure high level of functional properties and service life of the deforming tool.

#00129

Microstructure evolution of nickel-based superalloys induced by thermomechanical processing - simulation and verification

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It is known that different parts of the gas turbine engine discs are operated at different temperature and load. Therefore, it is advisable to make such components out of nickel-based superalloys with a regulated structure that provides them the best operational properties. It is important to know the thermomechanical treatment for their processing to form such structures. Research of the deformation behavior and the microstructure evolution of nickel-based superalloys were carried out on small specimens. The accumulated strains and the stress distribution in specimens were determined during simulation. A correlation between the specific strain work and the size of the recrystallized grains was established taking into account the isothermal deformation, the low thermal conductivity of superalloys, and the predominant distribution of the deformation work between heat generation and structure formation. It is possible to predict structure formation on the basis of a deflected mode. Verification was carried out by isothermal upsetting of specimens out of superalloys at the temperature and strain rates determined by simulation. Thermomechanical treatments of the superalloys for different microstructure formation were defined. The features of the microstructure formation are shown depending on the chemical and phase composition of the alloys. Hot deformation of the ATI Allvac 718Plus superalloy leads to dissolution of the gamma prime phase that facilitates the deformation capacity. Increasing the alloyage of superalloys, including rhenium, leads to formation of a necklace structure instead of a homogeneous fine-grained structure for less alloyed superalloys at the same strain.

#00113

Effect of grain size and thermomechanical conditions on the activation energy for super plastic flow in Zn-22Al alloy

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The application of the unified physics is the way to understand the phenomenology and mechanics of super plastic flow (SPF). In this scenery, the main proposed in this work is to establish the effect of grain size and thermomechanical conditions on the activation energy for super plastic flow (Q_{SPF}) in Zn-22%Al eutectoid alloy by applying the quantum mechanics and relativistic model (QM-RM) proposed by Muñoz-Andrade. Analyses on the experimental results reported before by some authors, it is shown for grain size of 0.35 μm that the calculated Q_{SPF} by using QM-RM for grain boundary sliding is 55.669 kJ/mol at 303 K and strain rate of 1 s^{-1}. These results are in closed agreement with the value of Q_a = 54 kJ/mol reported previously by using the theoretical and conventional methodology set up by Mohamed and Langdon. However, for grain size of 0.8μm, the calculated Q_{SPF} is 67.864 kJ/mol at 473 K and strain rate of $1x10^{-2}$ s^{-1}. Furthermore, in order to understand the phenomenology and mechanics of SPF in Zn-22%Al eutectoid alloy, the variation of the activation energy with the temperature; stress and strain rate is analyzed in association with coupled mechanisms during SPF, such as grain boundary sliding, cooperative grain boundary sliding and self-accommodation process related to the microstructure.

#0090

Influence of structural-phase state on low-temperature superplasticity of ultrafine-grained titanium alloys

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The mechanical behavior of ultrafine-grained (grain size d <1 μm) alloys during superplastic deformation is determined not only by the grain size but also by the structural-phase state with nonequilibrium grain boundaries having increased diffusivity. In the present work the effect of the structure and phase composition on tensile behavior of alpha plus beta titanium alloys with ultrafine-grained structure obtained using the *abc* pressing technique has been studied in a wide temperature range (823-1173K). It has been shown that the formation of an ultrafine-grained structure with an average size of grain-subgrain structure about 0.2 μm leads to decrease in temperature beginning of superplasticity up to 823K (~0.4 T_m) regardless of the chemical and phase composition of these alloys. However, the nature of the β-phase allocation has a significant effect both on the temperature range of the superplasticity realization and the maximum values of elongation to failure of the titanium alloys. It is shown that for Ti-4Al-2V and Ti-6Al-4V alloys the non-monotonic temperature dependence of the relative elongation is observed. At the same time, for the Ti-5Al-5Mo-5V-1Cr-1Fe alloy the considered dependence has the form typical for superplastic materials with a maximum elongation to failure exceeding 1700%. It has been established that this effect is associated with the features of the evolution of structural-phase state of the alloys due to the difference in their phase composition and the degree of nonequilibrium of grain boundaries.
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#0058

Molecular dynamics simulation of nonequilibrium grain boundaries in ultrafine-grained nickel and their relaxation under the action of ultrasound

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Numerous experimental studies since 70-ths of the last century have shown that nonequilibrium grain boundary (GB) structure caused by the absorption of extrinsic grain boundary dislocations (EGBDs) plays an important role in superplasticity of fine grained alloys and in mechanical properties of ultrafine-grained (UFG) materials as well. A prominent contribution to these studies and dislocation modelling of nonequilibrium GBs has been made by Prof. O.A. Kaibyshev and his co-workers. So far, however, no atomistic models of polycrystals with nonequilibrium GBs have been available, while these models would allow one to obtain new results on the structure, energy, kinetic and mechanical properties of UFG materials. In the present talk, results of molecular dynamics simulations of nanocrystalline nickel the GBs of which contain EGBDs will be presented. A special procedure is proposed to construct the initial structures of nanocrystals with EGBDs of different densities on selected GBs. The procedure is realized on a model columnar nickel nanocrystal with the column axis [112], which contains tilt GBs and allow for slip of edge dislocations of a single slip system with dislocation lines parallel to the column axis. Atomic structures of nanocrystals with different levels of nonequilibrium at temperatures 0 and 300 K are found by simulations and atomic energy maps are constructed, which show the existence of long-range stress fields in the grains typical for nonequilibrium GBs. Relaxation of the GBs under the influence of ultrasound is studied. Mechanical properties of nanocrystals with equilibrium and nonequilibrium GBs in tension are compared.

#0027

On mechanisms of "grain boundary sliding", in light of the Kaibyshev-Valiev data on two limit "nonequilibrium" GB states in deformed metallic materials

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In the light of data [1, 2] on two limit (extreme) "nonequilibrium" grain boundary (GB) states in deformed metallic materials, along with other ones, including data [3-5] on some mutual turning of grains during superplastic deformation of materials (the liquid-like Newtonian flowing, rheologically), mechanisms of the so-called "GB sliding" are considered. As is shown in [6-10], a cyclic three-stage process of structural and phase changes in the state of high-angle grain boundaries (caused by interaction with coming lattice dislocations and/or other defects) between three extreme states denoted as GB_1 (the "equilibrium" low-energy (crystalline) state I), GB_2 (the limit "nonequilibrium" high-energy (crystalline) state II), and GB_3 (the limit "nonequilibrium" high-energy (liquid-like) state III) can take place in deformed metallic materials under certain conditions of deformation. Here, the grain boundaries with negligibly low densities of trapped lattice dislocations correspond to state I (GB_1); the grain boundaries with the extreme high densities of trapped lattice dislocations (whose energy is close to the change in the free energy during the melting of the material at temperature of deformation) correspond to state II (GB_2); and the liquid-like grain boundaries correspond to state III (GB_3).

Thus, in the light of data [1, 2] and [3-5], according to [6-10], in deformed (deforming) materials some part of grain boundaries can be in state I, some part – in state II, and some part – in state III. And the "GB sliding" is mainly related to the mutual turning of grains along GB_3 during deformation.

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#00161

Analysis of the effect of the UFG structure, produced by equal-channel angular pressing, on the fatigue properties of the steel EI-961Sh

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It is known that high chromium martensitic steels can operate for a long period of time at temperatures up to 600°C. The formation of an ultrafine-grained structure can increase the strength and fatigue properties in many metals and alloys. At the same time, in martensitic steels the presence of dispersed particles and hard-to-deform martensite laths complicates the possibility to produce defect-free integral billets with an ultrafine-grained structure. It is shown in the present paper that in the process of equal-channel angular pressing, an ultrafine-grained structure with a mean grain size of 350 nm is formed in the martensitic steel EI-961Sh(C-0.14%Cr-11.53%W-1.66%Ni-1.63%Mo-45%), the mean size of dispersed particles is 60 nm, the volume fraction of which grows in the process of equal-channel angular pressing from 1.5% in the initial state to 3%. As a result of ultrafine-grained structure formation, the ultimate tensile strength grows to 1100 MPa.

In the ultrafine-grained samples, the fatigue endurance limit on the basis of 10^7 cycles has increased by 20%, from 472 MPa to 570 MPa, as compared with the coarse-grained sample. We have considered the main differences in the behavior of ultrafine-grained and coarse-grained samples with the help of fractographic analysis of fracture surfaces.

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#00138

The investigation of the microstructure evolution and mechanical properties of Ti/TiB and Ti-15%Mo/TiB composites produced by spark plasma sintering during the hot rolling

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Due to high strength-to-density ratio, excellent corrosion resistance and good biocompatibility titanium and titanium alloys are attractive for various applications, including the aerospace, automotive, chemical and biomedical industries. But strength of low-alloyed pure titanium can be insufficient for application in high-load bearing structures. Synthesis of titanium-based composites using titanium boride (TiB) as a reinforcing component is a promising method for hardening of pure titanium. TiB can be obtained in situ during spark plasma sintering (SPS). The Ti/TiB composites have generally high strength, but low ductility which limits their potential applications. Unfortunately the composites based on the alpha-titanium shows a low plasticity. To improve properties of the composites, beta titanium alloys can be used. One of the feasible candidates is the pseudo beta Ti-15Mo alloy. Hot or warm working of the MMCs can result in some increase of the low-temperature ductility. The aim of current investigation is to establish the effect of thermomechanical processing (hot rolling) on structure and properties of the Ti/TiB composite. The Ti/TiB and Ti-15%Mo/TiB composites were produced by SPS at 1200°C of a mixture of commercially pure Ti and 10 wt.% of TiB_2 powders. During rolling at the 900°C the TiB whiskers broke and aligned along the strain direction. Considerable decrease in grain size of the matrix during the rolling occurred. The microstructure refinement leaded to an increase in microhardness of the matrix by 10% (~50 HV). A comparative analysis of the microstructure evolution and the mechanical properties of the Ti/TiB and Ti-15%Mo/TiB composites was carried out.

#0098

Arrhenius-type constitutive equation model of superplastic deformation behaviour of different titanium alloys.

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Modelling and predicting the flow behaviour of metallic materials subjected to superplastic deformation is mandatory for providing a useful information about the metal forming process. This supplied information helps the designers for reducing time and cost by choosing the appropriate deformation conditions based on the model results. The current study develops a constitutive model for superplastic deformation behaviour of different titanium alloys (Ti-4Al-1V-3Mo, Ti-6Al-4V and Ti-2.5Al-1.8Mn). In order to determine the superplastic deformation regime of each alloy, the test with step by step decreasing of the strain rate was involved. The constant strain rate tests for Ti-4Al-1V-3Mo alloy in a temperature range of 750-900 °C and a strain rate range of 1×10^{-4} to 1×10^{-2} s^{-1}, for Ti-6Al-4V alloy in a temperature range of 800-900 °C and a strain rate range of 3×10^{-4} to $3\times10^{-3}s^{-1}$, and for Ti-2.5Al-1.8Mn alloy in a temperature range of 840-890 °C and a strain rate range of 2×10^{-4} to $8\times10^{-4}s^{-1}$ were conducted. The experimental tensile tests were used to develop the hyperbolic sine Arrhenius-type constitutive models for each alloy. The performance of developed model for each alloy was evaluated in terms of the correlation coefficient (R), the mean absolute relative error (AARE) and the root mean square error (RMSE). The values of R, AARE and RMSE are 96.3%, 10% and 4.33, respectively for Ti-4Al-1V-3Mo alloy, for Ti-6Al-4V and 97.3%, 3.4% and 1.09 in case of Ti-2.5Al-1.8Mn. The results revealed that the predicted stresses have a good agreement with the experimental stresses for all investigated alloys.

#0017

Advanced bimodal microstructure in a 316L austenitic stainless steel

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The development of bimodal microstructure in 316L austenitic steel subjected to large strain cold rolling and subsequent annealing and its effect on the mechanical properties were studied. The cold rolling was accompanied by a strain-induced martensitic transformation and grain refinement. The strain-induced martensite comprised 25% after rolling to a total strain of 3. The deformation microstructures consisted of flattened austenite and martensite grains with the transverse grain sizes of about 150 nm and 100 nm, respectively. The steel with nanocrystalline structure exhibited high yield strength ($\sigma_{0.2}$= 1680MPa), but low total elongation (δ = 5%). The subsequent annealing was accompanied by austenite reversal, static recrystallization and grain growth. The annealing at a temperature of 700°C (2 hours) led to a fully austenitic structure with bimodal grain size distribution. This bimodal microstructure consisted of individual micrometer-sized grains surrounded by the nanocrystalline matrix. The development of bimodal microstructure resulted in an increase of the total elongation above 15% while maintaining high strength ($\sigma_{0.2}$ = 960 MPa).

#00194

Mechanical behaviour of Al-Zn alloy after severe plastic deformation

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High pressure torsion and equal channel angular pressing in parallel channels at room temperature are used to form homogeneous ultrafine-grained structure with a grain size of the aluminium matrix of 350 and 700 nm, respectively, in Al-30Zn (wt. %) specimens. The ultrafine-grained samples with special geometry produced from the specimens processed by severe plastic deformation techniques were subjected to sphere-shaped dimple extrusion testing (via the Erikson test method) and bended plate extrusion to determine the material formability to shape forming during cold sheet metal forming. The same tests were performed on the material with coarse-grained structure for the sake of comparison. The obtained results are discussed.
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#00139

The effect of spark plasma sintering temperature on the microstructure and mechanical properties of the Ti-15%Mo/TiB composite and mechanical behavior of the composite during high-temperature compression tests

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Microstructure and mechanical properties of TiB - reinforced titanium matrix composites produced by the spark plasma sintering were studied. Ti-15%Mo/TiB composite was synthesized by chemical reaction between TiB_2, Ti and Mo during the SPS process at 1000°C and 1200°C at 40 MPa for 15 min. Chemical compositions with 3 and 5 wt.% TiB_2 amount were used. The effect of the temperature and chemical compositions with TiB_2 on the structure, morphology, interphase boundaries and mechanical properties of composite was investigated. The microstructure of the Ti-15%Mo/TiB composite was investigated by scanning electron microscopy. During SPS, an in situ chemical reaction between TiB_2, Ti and Mo resulted in the formation of nanometer TiB whiskers. The tensile testing of the samples composite at temperature range of 20°C - 700°C and an initial strain rate of $10^{-3}s^{-1}$ was conducted to determine the brittle-to-ductile transition temperature. The mechanical behavior and microstructural response of the composite to uniaxial compression in the temperature range from 20 to 1050°C was studied.

#00160

Modelling of tensile twin interaction with obstacles in magnesium

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Deformation twinning is common phenomena in magnesium and its alloys. Abundant twinning can lead to formation of structure inhomogeneity during severe plastic deformation of these materials. Such inhomogeneity can be serious limitation for application of ultrafine grain materials and for occurrence of superplasticity. One of possible way to suppress the twinning is inhibition of their growth by interaction with obstacle such as precipitates. Present study is devoted to atomistic modelling of interaction between growing tensile twin in magnesium and three dimensional obstacles.

#00195

Strengthening of the metastable Ti-34Nb-4Ta-7Zr alloy by severe plastic deformation through optimizing secondary phases precipitation

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Metastable β-titanium alloys of the Ti-Nb-Ta-Zr system have excellent biocompatibility, high corrosion resistance and low elastic modulus. However, the relatively low strength in a single-phase β-state constrains their use for the production of medical implants. Hardening of the alloy by conventional methods of thermomechanical processing inevitably leads to a decrease in plasticity and an increase in the elastic modulus due to the secondary α- and ω-phases precipitation. One of the approaches of increasing strength with maintaining a ductility margin and a low modulus of elasticity is severe plastic deformation, which has a significant influence on the phase transformations in titanium alloys.
This paper is devoted to the investigation of the processes of grain refinement and phase transformations occurring in the metastable β-alloy Ti-34Nb-4Ta-7Zr at high pressure torsion and equal channel angular pressing (ECAP).The non-monotonic character of the variation of the ω-phase volume fraction of the ω-phase with an increase in the accumulated strain degree is revealed. A grains refining, a boundaries structure, the role of α- and ω-phases in the formation of the strength and elastic properties of the nanostructuring alloy are discussed. The formation of an ultrafine-grained structure with a minimum content of ω-phase (less than 5%) in the alloy by the ECAP method at a temperature of 150°C succeeded in increasing the tensile strength from 450 to 740 MPa with a elongation of not less than 15%.
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Invited #00180

On the Origin of Structural Superplasticity in Different Classes of Materials

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This model assumes that grain/ interphase boundary sliding (GBS) controls the rate of optimal superplastic deformation. At the low stresses, elevated temperatures and fine grain sizes involved, intragranular dislocation motion, Nabarro-Herring and Coble creep are shown to be insignificant. GBS develops to a mesoscopic scale and leads to the formation of plane interfaces. The accommodation process depends on material composition, microstructure, nature of boundary obstacles and experimental conditions and could either be emission of dislocations from the sliding boundaries or highly localized diffusion. Significant and simultaneous sliding along different plane interfaces and their interconnection leads to superplasticity. Mathematical development results in a rate equation for steady state superplastic flow, which helps one to describe the phenomenon in terms of FOUR "universal" constants, viz. mean strain associated with a unit boundary sliding event, $gamma_0$, specific grain boundary energy, $gamma_B$, the average number of boundaries that align to form a plane interface for mesoscopic boundary sliding, N and a grain-size- and grain shape- dependent constant that lies between 0.1 and 0.5, "a". By analyzing data concerning 25 materials of different classes and grain sizes ranging from a few nanometers to several micrometers, one obtains that $gamma_0$= 0.126, $gamma_B$ = 0.734 Jm^{-2}, N = 7.5 and a = 0.230. **In conjunction with the regression equations of Frost and Ashby to predict the shear modulus of any material, these constants allow one to predict accurately the steady state strain rate of any superplastic material, including those whose superplastic response is yet to be evaluated.**

#0013

Tensile Deformation of Reversely Transformed Ultrafine Grained TRIP-aided Stainless Steel

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Ultrafine grained (UFG) TRIP-aided stainless steel (STS) was prepared by cold rolling and subsequent reverse transformation (TRIP: TRansformation Induced Plasticity). The steel consists of either a mixture of UFG martensite and austenite or full UFG austenite depending on reverse transformation temperature. Tensile deformation of the UFG STS is characterized by high yield strength and prolonged yield point elongation (YPE). After YPE, extensive strain hardening occurs. At the initial stage of YPE, relatively wide stacking faults appear uni- or bi-directionally within UFG austenite grains. At the later stage of YPE, very fine epsilon martensite bands are formed. Deformation after YPE is dominated by TRIP. This type of UFG TRIP-aided steels exhibits excellent combinations of high strength YS over 700 MPa and TS over 1200 MPa) and large elongation over 30 %. However, by increasing the reverse transformation temperature, the microstructure mainly consists of coarse austenite grains and therefore TRIP occurs from the early stage of deformation without YPE. Microstructural evolution during processing will be also discussed.

#00106

On the hierarchy of structural-phase states of 1561 Aluminum alloy

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An experimental issue of studying the structural and deformation properties of an initially anisotropic 1561 alloy within a wide temperature-speed range is considered. In the course of realization of the experiments on Gagarin samples cut out in the rolling direction, the circular cross sections of the samples took an elliptical form. As a macro-characteristic of the material reflecting the occurring structural changes, the anisotropy index (coefficient) is taken, which is represented by the ratio of deformations measured along the small and large axes of the cross section. Previously unknown regularities of the change in the anisotropy index were established at the temperature increase under different values of the degree and strain rate. An essential dependence of the anisotropy index on the thermomechanical conditions of deformation is noted. At high homological temperatures, the thermal range corresponding to the manifestation of superplastic properties is identified. Here, the anisotropy index tends to a minimum value. A correspondence between the results of mechanical experiments and the study of the structural state of the alloy was established. The obtained results indicate the dependence of the anisotropy parameter on the initial structure of the alloy. The anisotropy coefficient can be taken as one of the macroparameters of the material that correspond to structural transformations and allow one to quantify the degree and completeness of structural changes relative to the initial state in a changing field of temperatures and strain rates.

Invited #00181

On the Nuances in the Power Law Description and Interpretation of High Homologous Temperature Creep and Superplasticity Data

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“Power law’’ representation is used to describe minimum creep rate and steady state superplastic deformation. In creep isothermal log stress – log strain rate relationship is linear for constant rate controlling mechanism. During superplastic flow the slope of this curve changes even when there is no change in mechanism, i.e. the stress exponent, n, is a function of strain rate. Experiments reveal that for constant mechanism in both the phenomena n decreases with increasing temperature. Grain size has no effect on creep, but its effect is profound in superplasticity. Therefore, analyzing creep and superplasticity data by treating n for any given mechanism as a constant independent of stress and temperature is questionable. Here stress is normalized with respect to a reference stress, rather than the shear modulus. The microstructure dependence comes through the Buckingham Pi theorem. When contribution from microstructure terms to isothermal strain rate is constant, Laurent’s theorem helps generate a set of values for n. The simplest solution, viz. n is independent of stress, but is a linear function of temperature, describes steady state creep. (The case n is independent of both stress and temperature follows as a special case.) The second simplest solution, viz. n is a linear function of both temperature and stress describes steady state superplasticity. Using the equations, the values of n, activation energies for the rate controlling processes and strain rates at different temperatures and stresses could be estimated for both creep and superplasticity. The analysis is validated using experimental results concerning many systems.

#0086

Modification of the shear-compression specimen and development of a special technique for the physical simulation of asymmetric rolling with a large strain

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Physical simulation of the stress-strain state and microstructure evolution, which are similar to that occurring during asymmetric rolling with a large strain, is very important for design of technologies of producing ultra fine grained metallic materials. This paper presents the results of optimization of specimen geometry and a special multi-cycle shear-compression technique for the physical simulation of asymmetric rolling with a large strain up to e = 5. The specimen consisted of a parallelepiped having an inclined gauge section created by two diametrically opposed semi-circular slots which were machined at 45°. The specimen was compressed between two flat dies during shear-compression testing in accordance to the special multi-cycle scheme. Each cycle of the shear-compression testing consisted of two steps. The first step included height reduction of specimen, after that specimen was rotated by 90º. The second step included length reduction of the specimen for getting the quasi original shape of a parallelepiped. The specimen provided simultaneous pure and simple shear in an inclined gauge-section. The level of effective strain was controlled through adjustment of the specimen geometry, height reduction, load application direction and number of cycles of shear-compression. Height of the specimen, section dimensions, gauge thickness, width and radius were optimized by finite element method with using of software DEFORM 3D. Numerical simulation and comparison of the stress-strain state during shear-compression testing and asymmetric rolling of low-carbon steel AISI 1010 were performed. Results of FEM analysis of the applicability of the multi-cycle shear-compression testing to the modeling of asymmetric rolling are discussed.

#0070

Effect of Friction-Stir Processing on Microstructure and Corrosion Behavior of a Low Carbon Steel Used in Ship Panel Construction

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Grain refinement is well known method for improving different properties of metallic materials without affecting their chemical compositions. Among them, friction Stir Processing (FSP), which is based on the basic principles of Friction Stir Welding (FSW) technique, has been recently developed especially for modification of thin-layered surface microstructure by severe deformation- and recrystallizing-induced grain refinement. Many studies can be found on microstructural alterations and mechanical characterization during FSP, but very limited studies have been performed on corrosion behavior of FSPed steels. Therefore the mean purpose of this study is to evaluate the effect of microstructural alterations by FSW on corrosion behavior into the stir zone of a low carbon marine steel plates (ASTM 131A). FSP decreased the ferritic grain size of that steel from 25 µm to about 4 µm, and the grains are separated mostly by high angle boundaries with low amount of dislocations. Because of such intense microstructural alteration, the hardness of steel increased from 140 Hv to about 200 Hv, and the yield strength increased from 256 MPa to about 334 MPa. More importantly, corrosion resistance increased significantly after FSP due to improved pitting corrosion resistance arising from finer microstructure. After FSP, current density and corrosion rate values decreased from $4{,}44 \times 10^{-6}$ A/cm^2 to $3{,}86 \times 10^{-6}$ A/cm^2 and 1,75 mpy to about 1,32 mpy, respectively.

#0069

Mechanical properties and fracture features of 12 % Cr ferritic-martensitic steels EK-181, ChS-139 and EP-823 in the temperature range of 20-720 °C

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The features of the microstructure, structural-phase transformations and regularities of the change in the short-term mechanical properties of the ferritic-martensitic 12 % Cr steels EK-181, ChS-139 and EP-823 together with the features of their plastic deformation and fracture at the active stretching in the temperature range from 20 to 720 °C have been investigated. The change in plasticity regularities and the steel fracture mode are closely related to the features of the temperature dependence of the yield stress. In the region of temperatures from 20 to 450 °C these features are determined by the temperature dependence of the dispersion hardening value by nanoscale particles V(C, N). In the temperature range from 450 to 720 °C the acceleration of strength decrease with increasing temperature is observed. Reducing of the steels strength properties in this interval is associated with a decrease in the Orovan stress due to thermal activated processes to overcome nanoscale particles by sliding dislocations. At a significant increase in plasticity the complete elimination of brittle fracture and increase by an order of magnitude the sizes of ductile fracture cups as compared to room temperature are observed. At $T \approx 400$ °C the temperature dependence of the relative elongation to failure minimum is observed, the appearance of which is due to the effects by dynamic deformation aging.
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#0087

FEM simulation of influence of asymmetric cold rolling on through-thickness strain gradient in low-carbon steel sheets

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Grain refinement by severe plastic deformation can make conventional metallic materials several times stronger, but it leads to dramatic loss of their ductility. Gradient structure through the thickness of processed material represents a new strategy for producing a superior combination of high strength and good ductility. In gradient metallic materials the grain size increases gradually from nanoscale at the surface to coarse-grained in the core. Strain gradient can be considered as a mechanism of creating of such microstructures. Providing of predetermined strain gradient in metallic materials can be achieved by asymmetric rolling (AR), when circumferential speeds of the top and bottom work rolls are different. Since the AR is a continuous process, it has great potential for industrial production of large-scaled sheets. Searching the optimal process parameters which provide special strain gradient through sheet thickness is very important. This paper presents the distributions of the effective strain through sheet thickness of low-carbon steel AISI 1010 processed by a single-pass AR. Influence of thickness reduction (5…60%), work rolls speed ratio (1…60% with step 1%), diameters of the rolls (50…500 mm), Coulomb friction coefficient (0.1…0.4 with step 0.05) and initial strip thickness (1…8 mm) were investigated by the finite element method with using software DEFORM 2D. The non-linear effect of work rolls speed ratio on the strain gradient during AR was found. FE analysis of the deformation characteristics, presented in this study, can be used for optimization of the AR process as a method of fabrication of metallic materials with gradient microstructures.

Invited #0071

Room Temperature Superplasticity in Fine/Ultrafine-Grained Zn-Al Alloys with Different Phase Compositions

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Three Zn-Al alloys, namely Zn-22Al, Zn-5Al and Zn-0.3Al, in different phase structures were subjected to equal-channel angular pressing/extrusion (ECAP/E), and the effect of ECAP on the microstructure and room temperature (RT) superplastic behaviour of these alloys were investigated in detail. ECAP remarkably refined the microstructures of three alloys as compared to their pre-processed conditions. While the lowest grain size was achieved in Zn-22Al alloy as 200 nm, the grain sizes of Zn-5Al and Zn-0.3Al alloys were ~540 nm and 2 μm, respectively, after ECAP. After the formation of fine/ultrafine-grained (F/UFG) microstructures, all Zn-Al alloys exhibited superplastic behaviour at RT and at high strain rates. The maximum superplastic elongations were achieved as 400%, 520% and 1000% for Zn-22Al, Zn-5Al and Zn-0.3Al alloys, respectively. It is interesting to point out that the highest RT superplastic elongation was obtained in FG Zn-0.3Al alloy with the largest grain size, while UFG Zn-22Al alloy having the lowest grain size showed the minimum superplastic elongation. This paradox in elongation to failure values of the alloys was attributed to the different phase compositions of alloys. The formation of Al-rich α/α phase boundaries, which is less effective in grain boundary sliding comparing to Zn-rich η/η and η/α phase boundaries of Zn-Al alloys, is the lowest level in Zn-0.3Al alloy among all alloys. Therefore, it can be concluded that if it is desired to achieve high superplastic elongation even at RT for Zn-Al alloys, keeping Al content at a passible minimum level seems to be the most suitable way.

#00159

Radiation resistance of a FeCrW model alloy nanostructured by severe plastic deformation

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The origin of the microstructural changes under irradiation is the super-saturation of point defects that can agglomerate in the form of loops or voids and can enhance or modify solute atom diffusion, resulting in enhanced or induced precipitation or segregation.
In ultrafine grain (UFG) alloys, the volume fraction of grain boundaries is dramatically higher than in coarse grain (CG) materials. Since grain boundaries act as point defect sinks, a large part of irradiation induced defects can be annihilated. Therefore, a limitation of radiation damage is expected.
The objective of the work presented here is to investigate the stability of a nanostructured FeCrW alloy under irradiation. A Fe-14%Cr-1%W model alloy was nanostructured by high pressure torsion in order to get grains of several tens of nanometers. Both CG and UFG alloys were ion irradiated at 400°C in JANNUS facilities. Their microstructures were characterized by transmission electron microscopy and atom probe tomography. Nanoindentation tests were performed to estimate irradiation hardening in both CG and UFG alloys.
This talk will describe experimental results. The effect of nanostructuration on the stability of the microstructure and the hardening will be discussed.

Invited #00124

Strengthening mechanisms in coarse- and ultrafine-grained materials under large plastic and superplastic deformation

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An overview of physical mechanisms responsible for strengthening in coarse-grained (CG) and ultrafine-grained (UFG) materials subjected to large plastic and superplastic deformation is given. It is shown that large deformation of conventional CG metals is accompanied with development of rotational modes of plasticity, which manifest themselves through fragmentation of grains, formation of deformation-induced misorientation boundaries and bands, and sometimes kink bands. These phenomena are discussed in terms of generation and evolution of partial disclinations as carriers of rotational plasticity in crystalline solids. Some typical disclination structures are demonstrated and characterized within the theory of elasticity in terms of their stress fields and strain energies. Their contributions to the strengthening of CG materials are also discussed. In the case of UFG materials, the grain boundary mediated processes come in play. Their high volume fraction and commonly non-equilibrium structure are the main factors for manifestation of specific mechanisms of plasticity typical for UFG materials. Among these are deformation twinning, grain-boundary sliding, grain rotation and stress-induced grain boundary migration. The most of these mechanisms are closely related to rotational modes of plasticity and effectively described in terms of generation, transformation and motion of partial disclinations. Some examples of their experimental observation and theoretical modelling are demonstrated and discussed. The role of grain boundary defects is also illustrated by theoretical models, which describe strengthening and softening of UFG materials under superplastic deformation.

Invited #00101

A vision of superplasticity through the eyes of Prof. Sherby. Special emphasis in Al alloys

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Prof. Sherby worked in the field of superplasticity for about 50 years. In this review, the findings and vision of this long term research are presented. The superplastic behavior of various materials, with special emphasis of aluminum alloys, as influenced by processing is analyzed. The microstructural changes during deformation are discussed to gain insight of the characteristics of the deformation mechanisms. Constitutive equations that Prof. Sherby proposed for grain boundary sliding and other competing mechanisms allow prediction of the controlling mechanisms during deformation.

#0062

Microstructure and Fatigue Properties of a Cr-Ni-Ti Austenitic Stainless Steel after Equal Channel Angular Pressing and Annealing

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The aim of the study was to investigate the effect of equal channel angular pressing (ECAP) and subsequent annealing on the microstructure and service properties of a metastable 17.3%Cr-9.2%Ni-0.7%Ti austenitic stainless steel. The microstructure was studied by light microscopy, TEM, XRD and EBSD analysis. After three ECAP- passes the oriented grain/subgrain structure with a size of structural elements of 100–250 nm that contained 30 vol. % of lath martensite appeared. Annealing in the temperature range of 450 – 600 °C after ECAP led to the formation of annealing twins, an increase in the strength, and a reduction in ductility. The change in the mechanical properties was attributed to the dispersed TiC particles, which were revealed after annealing at temperatures of 450-550 °C.
Dynamic twinning, martensitic transformation, dynamic recovery, and recrystallization took place in the processed steel during subsequent cyclic deformation in the course of fatigue tests according to the scheme of repeated tension. The fatigue strength increased after ECAP due to the grain refinement and twinning of an austenite structure and the appearance of martensite. The fatigue limit was maximal after ECAP and annealing at 550°C for 20 h due to the high density of annealing twins in a predominantly austenitic recrystallized matrix, intense dynamic twinning, and martensitic transformation during cyclic deformation.
The work was supported by the Russian Foundation for Basic Research (grant 16-08-00365).

#00190

Fundamental patterns of fragmented structures evolution during plastic deformation

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The fragmentation phenomenon has been thoroughly investigated based on systematic experimental and theoretical analysis of deformation-induced microstructure formed in commercially pure Al, Fe and Cu at different temperatures, strain rates and deformation methods (uniaxial compression, 2D-forging, equal channel angular pressing and dynamic channel angular pressing). The fragmented structure has been shown to form as a result of superposition of two primary physical processes: the fragmentation of crystal volumes, which had originally uniform orientation, and the fragmentation of original grain boundaries as well as twin boundaries.
More than hundred misorientation spectrums were considered for various metals and deformation conditions. At that, development of three characteristic components of these spectrums has been investigated. The first component is the peak located within the angular range from two 2 degrees to about 20 degrees. The second is the twining-related peak located within the range from 50 to 60 degrees. The third is the intermediate region of high-angle misorientations.

#00191

NanoSPD-related publication activity

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Nanostructured materials produced by severe plastic deformation techniques attract growing interest in the scientific community as well as in industrial and business circles all over the world and this phenomenon only tends to progress with years, which is easily proven by the vast number of international nano and, in particular, nanospd-related events held worldwide. In recent years the development of SPD techniques has become one the most attractive research directions in materials science, as SPD materials, such as bulk nanostructured materials, can provide new and unusual properties for a wide range of metals and alloys. With new research comes growing publication activity that for many institutions serves as a tool to assess both the efficiency and gains in scientific performance.

#0092

Hollow cellular structures from titanium sheet alloys for aerospace applications

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The success of creating promising aerospace technology is largely determined by how effectively and comprehensively the most advanced scientific achievements, progressive design and production solutions are realized. The development of new resource-saving technological processes using materials with high performance properties and providing for the production of lightweight hollow rigid and durable structures opens up wide opportunities for the creation of promising aerospace engineering. Studies conducted in recent decades abroad and in Russia show that high efficiency in the manufacture of multilayer hollow structures provides a technological process based on the combination of superplastic forming with diffusion bonding (SPF/DB). Currently, this technology is considered as one of the most promising, because it provides the flexibility to design and manufacture complex constructions with a mass saving of up to 30% while reducing the cost of manufacturing by about 50%. The paper describes the results of many years of research on the development of SPF/DB technology, conducted at the Institute for Metals Superplasticity Problems of the Russian Academy of Sciences, to obtain typical aerospace products such as hollow blades, wing and body panels. The latest results and prospects for the development of the technology of SPF/DS are discussed.

#0050

Effect of ultrasonic treatment on the characteristics of superplasticity of titanium alloy Ti-6Al-4V

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Superplastic deformation of ultrafine-grained (UFG) titanium alloys usually occurs at high flow stresses, which limit the possibilities of its practical applications. In the present work, we show that ultrasonic treatment of the samples of UFG alloy Ti-6Al-4V results in a reduction of their flow stress, increase of the strain rate sensitivity coefficient and elongation to failure during tensile tests in the conditions of low-temperature superplasticity. Comparative studies of mechanical properties are carried out on the samples of Ti-6Al-4V alloy processed by equal channel angular pressing (ECAP) and post-ECAP ultrasonic treatment (UST). The UST was carried out at a frequency of 20 kHz with the amplitude of oscillating tension-compression stresses 100 MPa. Tensile tests were carried out using the samples with a gauge length 10 mm, width 3.4 mm and thickness 1.5 mm at a temperature of 600 degrees Centigrade with strain rates in the interval 0.0001 to 0.001 1/s. As one could expect, a decrease of the strain rate led to a reduction of the flow stress, increase of elongation and strain rate sensitivity. The samples subjected to UST exhibited a superplastic behavior at higher strain rates. The samples processed by ECAP and ECAP+UST demonstrated strain rate sensitivity above 0.3 and elongation to failure above 300% at strain rates of 0.00017 and 0.0007 1/s, respectively. At strain rate 0.00017 1/s, the ultrasonically treated sample deformed in tension to the strain of 500% without failure with the maximum flow stress 30% less than that for the samples after ECAP processing.

#00126

Effect of Friction Stir Processing on Fatigue Behaviour of thin Dual Phase (DP-600) Steel Sheets

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In this study, effect of Friction Stir Processing (FSP) on the deformation behaviour of dual phase DP-600 steel sheets under static and cyclic loading conditions were investigated. Fatigue tests were performed on servo-hydraulic machine at a frequency of 15 Hz during repeated tension at a cycle asymmetry R=0 and up to 10^7 loading cycles. DP-600 steel reflected yield strength of about 300 MPa and reached to UTS of about 620 MPa with uniform elongation of 21 % and fractured after a total elongation of 34 % elongation in its as-received condition. After FSP, yield strength and ultimate tensile strength reached to about 811 MPa and 1053 MPa respectively. This effective strength enhancement brought about an acceptable decrease in uniform elongation and elongation to failure to about 6.3% and 13.0%, respectively. Based on achieved ductility values obtained, it can be considered that, FSPed DP-600 shows a deformation behaviour that mostly dominated by the strain hardening. Static strength enhancement obtained by FSP of DP 600 steel also improved fatigue behaviour. Fatigue test results indicated that, applied FSP process shifted S-N curve to higher stress levels and increased fatigue limit of the as-received DP 600 steel from 350 MPa to 480 MPa. Experimental results obtained in the study mainly indicate that, FSP is an easy to apply and practical thermo-mechanical procedure which provides significant enhancement on the mechanical performance of DP 600 steel under both static and cyclic loading conditions.

#0072

Thermal stability of microstructure and properties of Cu-0.5Cr-0.2Zr alloy subject sever plastic deformation in combination with cold rolling

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Copper and copper alloys are widely used in engineering as structural materials because they have high electrical and thermal conductivity. In connection with the rapid growth of industry, special requirements are imposed on these materials, that is, they must withstand the contact mechanical loads without significant plastic deformation at elevated temperature and have stable high physical and mechanical properties. To improve the combination of strength, electrical conductivity, thermal stability, and wear resistance, low-alloyed Cu-Cr-Zr copper alloys have been subject to severe plastic deformation and aging. It the same time the analysis of the termostabiliti of the formed ultrafine grained microstructure and properties is a topic talk. In this work, a Cu-0.5Cr-0.2Zr (wt. %) alloy was quenching to form solid solution, equal channel angular pressed and cold rolled with following aging. The microstructure was studied, mechanical and electrical properties were also analyzed. The results showed that the ultimate strength of the Cu-Cr-Zr alloy increases with the degree of deformation at room temperature to 630 MPa. Heat treatment at 450 ° C for 1 hour led to the precipitation of Cr and Cu_5Zr particles, which increases the strength to 660 MPa, which is 2.5 times greater than the initial state. At the same time, sufficient electrical conductivity of 70% IACS is maintained. The thermal stability of the microstructure and properties of the alloy are investigated. The reinforced alloy maintains stable the microstructure and microhardness at 450 ° C for at least 5 hours. The change in microhardness is no more than 10%. That is in agreement with the requirements of industry.

#00183

Low temperature and high speed superplastic flow in TZP by applied electric field

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Since the first report by Wakai *et al*. on superplastic deformation in a 3mol% Y_2O_3 stabilized tetragonal ZrO_2 polycrystals (3Y-TZP), significant numbers of studies have been carried out on superplastic ceramics. Industrial applications of superplastic ceramics, however, have still been limited. One of the major reason is the limited temperature and strain rate available for superplastic forming of ceramics: superplasticity in structural ceramics such as TZP appear at a high temperature in a range of 1400-1650ºC and a strain rate around 10^{-5}-$10^{-4}s^{-1}$. Previous studies demonstrated that the application of a direct current (DC) electric field to superplastic TZP was effective in reducing the flow stress and improving ductility at temperatures above 1450°C and a strain rate around $10^{-4}s^{-1}$; the reduced flow stress and improved ductility were attributed to the retardation of dynamic grain growth. We demonstrated that by applying strong electric field, TZP with the grain size of 0.4mm may exhibit superplastic flow at the furnace temperature of <1000ºC and the strain rate of $>10^{-3}s^{-1}$. Under $190Vcm^{-1}$, TZP exhibited the elongation to failure of 155% and the flow stress of lower than 20MPa at the furnace temperature of 800ºC and the strain rates of $2\times10^{-3}s^{-1}$. The furnace temperature and strain rate conditions for the superplastic flow are comparable to those in Ti-based superplastic alloys.

Keynote #0063

Local Accommodation Processes of Superplastic Gradin Boundary Sliding — Their Direct Observation in Two-Dimensional Grain Boundary Sliding

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Accommodation processes are crucial for grain boundary sliding in superplasticity, though their precise understanding has got little progress since several fundamental models proposed in 1970’s. The present study achieved two-dimensional grain boundary sliding in ODS ferritic alloy which had elongated and aligned grain structure, and observed the already-proposed accommodation models by diffusion and dislocation, respectively, depending on superplastic regions.

1) In Region II, diffusional accommodation was confirmed through observing the change in marking-line spacing, which indicates volume inflow or outflow at grain boundary. It was confirmed through vertical observation in FIB trench wall.
2) Between Regions II and III, dislocational accommodation inside of mantle region, as proposed by Gifkins, was confirmed through observing curve of marking lines near grain boundary.
3) In Region III, dislocational accommodation inside of core region, as proposed by Ball and Huchison, was confirmed through observing a slip line passing through a grain.

It is derived that superplasticity relies not on a single mechanism but on several diffusional and dislocational accommodations contributing depending on strain rate.

#00153

Towards prospective industrial application of nanoSPD materials

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Nowadays the world is facing a great innovative potential for bulk nanostructured materials (BNM). Markets for BNM appear to exist in every product sector where superior mechanical and physical properties (in particular, high strength, good strength-to-weight ratio, and excellent fatigue life) are critical. The developments of scientists from all over the world have made it attractive to apply nanometals in various industries including aerospace, transportation, medical devices, sports products, electronics, etc.
Institute of Physics of Advanced Materials of the Ufa State Aviation Technical University (IPAM USATU) initiated activities on fabrication of BNM by means of the severe plastic deformation technique in mid 90-s of the last century. The main materials for the R&D work served titanium and its alloys, steels, copper alloys and light alloys. Since then the outstanding results have been achieved and demonstrated, that is the basis for IPAM (www.nanospd.ru) to represent itself as one of the leading experts in producing and investigation of BNM. In particular a possibility of producing pilot batches of nanostructured titanium billets with the UTS $\geq$ 1250 MPa and fabrication of aluminum alloys with very high strength and conductivity have been demonstrated. Novel properties pave the way to innovative application of these materials. This report will demonstrate the most promising research lines from the point of view of commercialization.

#0054

Continuous dynamic recrystallization in dual-phase titanium alloy in superplasticity

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Dual-phase titanium alloy, Ti–4.5Al–2.5Cr–1.2Fe–0.1C–0.3Cu–0.3Ni (mass%), were deformed superplastically at 1073 K and 10^{-4} s^{-1}–10^{-1} s^{-1}, and microstructures were observed using SEM and EBSD. Continuous dynamic recrystallization was observed in region III, resulting in grain refinement from 4.2 and 2.8 micron to 2.4 and 2.3 micron in alpha and beta grains respectively. The grain size of the alpha phase decreased more than that of the beta phase. In the recrystallized microstructure, sub-boundaries formed perpendicularly to slip directions <11−20> in the alpha phase and parallel to slip planes {110} in the beta phase, which might be caused by the difference in the symmetry of the crystal structures.

#0060

Low temperature superplasticity of ultrafine-grained brasses alloyed with Si and Sn processed by equal-channel angular pressing

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CuZnSi and CuZnSn alloys in previously quenched state were subjected to 8 passes of equal-channel angular pressing (ECAP) via route B_C in a die with a channel intersection angle of 120° at temperatures of 350 and 400 °C on the samples with a diameter of 20 mm. ECAP leads to the formation of ultrafine-grained (UFG) structure with an average grain size from 290 to 480 nm, depending on the deformation temperature, and improves the strength properties. The tensile strength of CuZnSi alloy increases from 332 to 709 and 592 MPa after ECAP at 350 and 400 °C, respectively, compared to the initial quenched state. Herewith, the total elongation after ECAP at 350 °C remains practically unchanged, while the ECAP at 400 °C increases the elongation up to 21%. The alloy CuZnSn after ECAP at 350 °C is brittle and has broken in the elastic region, while tensile strength in the alloy after ECAP at 400 °C rises from 362 to 645 MPa with a significant decrease in total elongation.
Both investigated alloys show the ability to low-temperature superplastic deformation. The maximum elongation to failure of 937% is obtained in the alloy CuZnSi after ECAP at a temperature of 400 °C at a strain rate of 10^{-3} s^{-1} and a test temperature of 350 °C. An elongation of 633% is achieved in the alloy CuZnSn at similar treatment regime and testing conditions.

#0089

Comparative study of the ultrafine-grained structure 316L, 321 stainless steels and Ti-6-4 alloy produced by selective laser melting

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Selective laser melting (SLM) of powders is a promising technology to produce part with complex shape. The structure features is of great interest for many researches because metallic materials produced by SLM technology demonstrate rather high mechanical properties. Thanks to the ultra-fast crystallization during SLM process, the created parts should have an ultrafine grained or amorphous structure. Based on the obtained data, it can be concluded that the observed ultrafine-grained structure and crystalline anisotropy can be arised from the rapid motion of the laser beam, resulting in significant temperature gradients and high cooling rates. Formation of dendritic and columnar microstructure is typical for crystallization processes occurring at high temperature gradients.
In the present study the EBSD maps, crystalline structure features of the 316 and 321 austenitic stainless steels and titanium alloy Ti-6-4 are presented. The dependencies of the mechanical properties on the specific energy input during SLM process are discussed. The main assumption is that during SLM it is possible to produce metallic material with subgrain structure 0.7 – 0.9 mcm, which is promising for further investigation of superplasticity.

#007

On microstructure homogeneity in AA6063 alloy Processed by cyclic expansion extrusion

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Specimens of aluminium alloy AA6063 were subjected up to 10 passes at 200°C using the cyclic expansion extrusion (CEE) process. The die angle is 22.5°. The effects of the number of passes of CEE on the microstructure and mechanical properties of the AA 6063 alloy were investigated. The microstructural examination revealed grain refinement during the CEE process. The average grain size had decreased from 20 μm in the parent material to 4.82 μm after 10 passes. The EBSD images were taken at the outer and the middle regions of the specimen. Non-uniform grain refinement during the initial passes was evident. At the later stages, however, more homogenous grain refinement was present. The microhardness and tensile strength increase while the elongation decreases with the number of CEE passes. The hardness values measured on the surface of the specimen show continued improvement up to 10 passes. The hardness measured at the center of the specimen is of a slightly lower value. The tensile strength properties increase in magnitude up to six passes. After six passes the ultimate tensile strength (UTS) is 153MPa. With increasing number of passes an increasingly ultrafine grained (UGF) structure developed in the alloy and the fraction of high angle grain boundaries (HAGBs) also increased. At the end of 10 passes, the proportion of HAGBs in the material was 75%. Compared with other SPD techniques, the grain boundary orientations did not change much with the number of the pass in this case.

#0061

Effect of temperature of high pressure torsion on structure, texture, microhardness and thermal stability of Mg-Zn-Ca alloy

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The effect of the treatment temperature on structure, texture, microhardness and thermal stability of biodegradable alloy Mg-1%Zn-0.3%Ca was studied in this research. The alloy was processed by high pressure torsion (HPT) at room temperature, and at 100 ºC and 300 ºC. The microstructure examination showed that the deformation twins of 0.5 – 0.6 μm in size are present in the alloy after torsion at room temperature and at 100 °C. After torsion at 300 ºC we observed the formation of grain with an average size of 1.5 μm. The refinement of the structure leads to an increase in the microhardness of the alloy. The microhardness of the alloy on the half-radius of the disks after the HPT at room temperature was 970 ± 30 MPa, at 100 °C – 990 ± 30 MPa, at 300 °C – 735 ± 20 MPa in comparison with 528 ± 39 MPa in initial homogenized state. The study of the thermal stability showed that the alloy deformed at room temperature and at 100 °C can be further strengthened by aging at 150 °C. No additional hardening is observed during heating after homogenization and after torsion at 300 °C. The maximum hardening (150 MPa) during the aging at 150 °C for 1 h is achieved after torsion at 100 °C. During heating the alloy softening does not occur until 200 °C.
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#00132

Formation of duplex UFG structure in the 3d transition metals high entropy alloy and its impact on mechanical properties

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The so-called high-entropy alloys (HEAs) composed of at least 5 principal elements in nearly equiatomic concentrations have attracted considerable attention in recent years. HEAs can demonstrate promising properties like, for example, high hardness, wear resistance, corrosion resistance, high strength at elevated temperatures etc. However, obtaining balanced combination of properties, like, for instance, strength and ductility at room temperature, remains the unsolved task. One of the ways to considerably increase strength of the alloys without sacrificing the ductility is to refine the microstructure down to ultrafine-grained (UFG) scale. But production of UFG structure in HEAs is not frequently reported. Here we introduce a new HEA, based on the well-studied CoCrFeNiMn alloy, containing large amounts of Al and C. In the initial as-cast condition the alloy is composed of coarse-grained face centered cubic (fcc) matrix with insignificant fraction of M23C6 carbides. Cold rolling with subsequent annealing at 800-1000°C results in (i) precipitation of large fraction of B2 and M23C6 particles and (ii) recrystallization of fcc matrix. However, size of recrystallized grain remains in range 0.55-1.75 μm (depending on the annealing temperature), most probably due to the pinning be the second phase particles. As the result, duplex UFG structure is produced in the alloy after cold rolling and annealing. This structure promotes attractive combination of strength and ductility, for instance, yield strength of 530-850 MPa together with uniform elongation of 16-30%. Phase transformation and strengthening mechanisms of the alloy are discussed.

#0091

Fully coupled two-phase composite model for microstructure evolution during non-proportional severe plastic deformation

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A fully coupled micro-macro interaction model is proposed for the grain refinement caused by severe plastic deformation of cell-forming metallic materials. The model is a generalization of a previously proposed two-phase composite model suggested for the evolution of dislocation populations corresponding to the interior of the dislocation cells and dislocation cell walls, cf. [C.B. Silbermann, A.V. Shutov, J. Ihlemann, Modeling the evolution of dislocation populations under non-proportional loading. International Journal of Plasticity (2014)]. The evolution of the material microstructure depends on the applied hydrostatic pressure, process temperature, strain rate, and the loading path. Backstresses are used to define a measure of the strain path change; the model accounts for the dissolution of dislocation cells occurring shortly after load path changes. The large strain kinematics is modelled in a geometrically exact manner using the nested split of the deformation gradient. Within the extended model, the strength of the material depends on the microstructural parameters. The new model is thermodynamically consistent, objective, and w-invariant under isochoric changes of the reference configuration (cf. [A. V. Shutov, J. Ihlemann, Analysis of some basic approaches to finite strain elasto-plasticity in view of reference change. International Journal of Plasticity (2014)]). An efficient time integration of the stiff evolution equations is based on the numerical procedure, proposed in [A. V. Shutov, Efficient implicit integration for finite-strain viscoplasticity with a nested multiplicative split. Computer Methods in Applied Mechanics and Engineering (2016)]. Different ECAP routes are simulated numerically to demonstrate the impact of the strain path on the microstructure.

#0046

Mechanisms of grain refinement and strengthening during HPT of CrMnFeCoNi high-entropy alloy

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An equiatomic high-entropy alloy CrMnFeCoNi was severely deformed at room temperature by high pressure torsion (HPT) up to shear strains of about 170. Its microstructure and texture were analyzed by X-ray diffraction (X-ray line profile analysis and X-ray microdiffraction, respectively). It is shown that at a shear strain of about 20 a steady state domain/grain size of 24 nm and a dislocation density of 3×10^{16} m^{-2} is reached, while the twin density goes over a maximum of 2% at this strain. The texture developed is typical for sheared face-centred cubic metals, but it is extremely weak. Moreover, the microhardness was measured after HPT as a function of shear strain. The results will be discussed with regard to grain refinement and strengthening, including dislocation slip, twinning and grain boundary sliding.

#00163

Influence of pure copper and aluminum microstructure on thermoelastic and thermoelectric response under nanosecond laser impact

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The report will present the effect of processing by severe plastic deformation (SPD) on the thermoelastic and thermoelectric properties of pure aluminum and copper. The studies were carried out on technical aluminum AD1 (99.3%) and pure copper M1 (99.9%). High pressure torsion (HPT) and equal-channel angular pressing (ECAP) were used for processing by SPD. After the SPD processing, the materials samples in the form of plates were subjected to laser radiation focused on the plate center. Pulsed lasers with a wavelength of 1.06 micron and operating in the free laser oscillation mode with pulse duration of 100 microseconds or in the mode of a single pulse with duration of about 10 nanoseconds were used. The thermoelastic and thermoelectric responses of the materials was determined by measuring the thermoelectric power. The plates with the initial coarse-grained material state were considered as a reference sample, and the plates of the materials after SPD processing were considered as a controlled object. The results demonstrated a very high sensitivity of the parameters of thermoelastic and thermoelectric response to structural changes in the materials. For example, the used HPT mode led to a reduction in the maximum thermopower value for aluminum by 40% and for copper by 35%.

#00112

Superplastic behavior of β-solidifying TiAl based alloy

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Mechanical behavior and microstructure evolution of as cast Ti-44Al-2V-1Nb-1Zr-0.2B-0.2Gd alloy were studied at temperatures of 900-1250°C and strain rates of 0.001-1 s^{-1}. Following phase fields: (α_2+γ), (α+γ), (α) and (α+β) during heating of alloy were revealed. Microstructure analysis after deformation and mechanical behavior allowed defining main processes of structure formation. Two temperature intervals with different mechanical behavior were found: the first one was corresponded to the (α_2+γ)-phase field (900-1100°C), where the microstructure had mainly a lamellar morphology, and the second interval comprised the (α+γ)-, α- and (α+β)-phase fields (1150-1250°C), in which the α-phase dominated. In the first interval, mechanical behavior was typical of a lamellar structure and was associated with the transformation of the lamellar structure into globular one. In the second interval, mechanical behavior was similar despite changes in phase composition. Deformation in all phase fields led to microstructure refinement due to dynamic recrystallization and superplasticity manifestation. The strain rate sensitivity m demonstrated the most pronounced dependence on a strain rate at temperatures corresponded to the (α_2+γ)- and (α+β)-phase fields. At T=1100°C and $\acute{\varepsilon}$=0.05 s^{-1} the maximum strain rate sensitivity m was of 0.40. At T=1250°C and $\acute{\varepsilon}$=0.5 s^{-1} the maximum strain rate sensitivity m was of 0.59. The relationship between coefficient m value and microstructure formed was discussed.

#00155

Inverse characterization of a superplastic aluminium alloy from full field experimental data

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The main features of an effective procedure for the characterization of superplastic materials are reliability, accuracy of the results and easy availability of the required experimental data. In addition, reducing the number of the experimental tests is certainly a viable way to increase the efficiency of the characterization procedure aimed at optimizing the forming process.

In this work, we explore the feasibility of performing an inverse analysis by using the full field strain experimental data obtained from a 3D-digital image correlation (DIC) measurement of a free inflation test. The aim of the inverse analysis is to find the material constants by simulating the experimental test with a finite element model. Material constants are the unknown parameters to be found by minimizing an objective function that quantifies the discrepancies between experimental and numerical data. We considered different formulations of the objective function and compared results and convergence rate of each approach. The availability of full field experimental data allowed to adopt different and separate objective functions for each material constant. This increased the rate of convergence in the inverse analysis without affecting the accuracy of the results.

#0039

Features of Creep of Titanium Alloy of Ti-Al-V-H System

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Comparative studies of creep in the fine- and ultrafine-grained Ti-6Al-4V and Ti-6Al-4V-0.23H alloys were performed at 723-873 K.
Hydrogenation of the Ti-6Al-4V alloy to a concentration of 0.23 w.% in both states is found to lead at 723 K to decrease in values of steady creep rate and ultimate strain and increase in time to failure. A feature of the deformation of the ultrafine-grained Ti-6Al-4V alloy in the steady creep stage is development of mesobands of localized deformation. Hydrogen in the ultrafine-grained Ti-6Al-4V-0.23H alloy suppresses the formation of the mesobands of localized plastic deformation, but leads to the development of superficial macrocracks.
The dependence of the steady creep rate on stress for the Ti-6Al-4V alloy in both states at 723 K is satisfactorily described by the creep power law. Hydrogen presence in the Ti-6Al-4V-0.23H alloy results in a failure of the creep power law.
As testing temperature rises, correlation between steady creep rates for the Ti-6Al-4V and Ti-6Al-4V-0.23H alloys is determined by the possibility of hydrogen degassing from sample during testing. Steady creep rate for the Ti-6Al-4V-0.23H alloy in both states under the creep and simultaneous hydrogen degassing is higher as compared to their unhydrogenated counterparts. This is due to the activation of grain boundary sliding and increase in its contribution to the total deformation.
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#0032

Microstructure Evolution and Mechanical Behavior in Coarse Grained and Nanostructured Shape Memory TiNi Alloy: A Comparative Study

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Influence of grain size on the martensitic transformation present in shape memory alloy $Ti_{49.3}Ni_{50.7}$ and its impact on mechanical properties is studied. The initial microstructure, its evolution with deformation and consequences for mechanical properties were focused on. Non-uniform deformation in the form of shear bands, sub-grain stacks within shear bands, observation of radial broadening in SAED inside the shear bands which could be due to commencement of martensite transformation or segregation of Ti_3Ni_4 in the B2 phase, areas between the shear bands consisting of nanograins of size 10 nm and their internal structure being free of dislocations and other forms of defects are the key observations. Post-deformation annealing (450 °C, 1h) leads to partial recrystallization and formation of grains of size 10-50 nm in the inter-bands regions. The phase composition is predominantly austenite, but zones of martensite in some grains are also seen. In coarse grained material, a true strain of 1.42 suppresses the martensitic transformation. Post-deformation annealing at 450°C ensures a uniform grain size distribution. The NS state has a higher σ_M, UTS and a smaller stress plateau than the CG state due to partial suppression of martensite transformation under deformation. Fractographic observations are also reported.
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#00115

Phase composition and properties of magnesium-ceramic composites after high pressure torsion

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The structure and the properties of an composite, consisting of Mg–Y–Nd–Zr alloy (WE43) and various oxides are studied. The WE43 powder is covered by nanocrystalline oxide layer by means of a wet chemical deposition process. After that the powder is compressed to solid samples and deformed using high pressure torsion at room temperature. A second phase is present in both pure WE43 alloy and the one with deposited oxides. However, the modification of the alloy by the oxide layer deposition and deformation by high pressure torsion changes the phase composition of the samples. The dependence of the grain refinement, grain boundary structure, microhardness and corrosion resistance on the phase composition is discussed.
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#00168

Ultra-fine grained titanium prepared by cryogenic milling and spark plasma sintering

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Gas atomized Ti Grade 2 powder was processed by cryogenic attrition in liquid argon. Powder particles undergo repetitive plastic deformation, resulting in grain refinement to ultra-fine grained (UFG) level. The subsequent consolidation was performed by spark plasma sintering (SPS) with the aim of preserving UFG microstructure in the bulk material. Several combinations of sintering time (1 to 10 min) and temperature (650 to 850 °C) was used to determine the effect of processing parameters on sample porosity, grain size and mechanical properties. Scanning electron microscopy, electron back-scattered diffraction (including EBSD in transmission mode – t-EBSD), x-ray diffraction, microhardness measurements and compression tests were used for characterization of prepared material. Significant plastic deformation occurred during attrition milling, with only little reduction in particle size. Powder grain size was reduced to below 100 nm. Minimum sintering temperature of 700 °C is required to achieve relative density > 99 %. Mechanical properties are mostly influenced by residual porosity after sintering and contents of contaminants (N and O), while grain refinement does not play a significant role as a hardening mechanism.

#00171

Effect of Precipitates on Thermal Stability of Ultra-Fine Grain Magnesium Alloy Prepared by Equal Channel Angular Pressing

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As-cast magnesium alloy WE43, containing yttrium and rare earth elements, was processed by equal channel angular pressing (ECAP). The processing led to a significant grain refinement together with a massive precipitation of the secondary phase particles. Thermal stability of the ultra-fine grain (UFG) structure together with microstructural changes due to exposure to elevated temperatures were studied by several complementary techniques in the temperature range of 160-500 °C. It was found that UFG structure consisting of grains with size of ~340 nm and high density of Mg_5RE particles is stable up to 280 °C for 1h of annealing. Moreover, only negligible change of the microstructure occurred after annealing for 16 h at 250 °C. Excellent thermal stability of UFG structure was caused by fine Mg_5RE particles, which suppressed the grain growth. Exceeding the thermal stability of these particles above 280 °C resulted in material softening.

#00141

Competition between Formation and Decomposition of Solid Solution in Copper-based Alloys under High Pressure Torsion

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The influence of high pressure torsion (HPT) on the formation and decomposition of solid solutions in several Cu-based alloys was studied. The Cu-based binary alloys with different alloying components were annealed (1) at high temperature where all (or almost all) atoms of a second component are solved in the Cu-rich matrix and (2) at relative low temperature where almost all atoms of a second component were precipitated. They form particles of a second phase surrounded by an almost pure Cu-matrix. The competition between deformation-driven precipitation and dissolution of precipitates took place during subsequent HPT treatment. The dynamic equilibrium between these two processes is reached already after 1.5-2 anvil rotations. The precipitates in samples (2) partially dissolved in the matrix during HPT. The solid solution in samples (1) partially decomposed. The resulted concentration of a second component after HPT was almost the same in samples (1) and (2). In other words, the equifinal state is reached during HPT. The composition of Cu-matrix in this *equifinal* state is equal to that which can be reached in *equilibrium* after long annealing at a certain temperature T_{eff}. T_{eff} increases with increasing activation enthalpy of diffusion of a second component and its melting temperature T_m. The work has been partially supported by the Russian Foundation for Basic Research (grants 18-03-00067 and 16-53-12007), Deutsche Forschungsgemeinschaft, the Russian Federal Ministry for Education and Science (Increase Competitiveness Program of NUST«MISiS»), National Science Centre of Poland (grant OPUS 2014/13/B/ST8/04247)

#0026

Conical shaped AZ31 Mg part formed via hybrid superplastic forming

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Hybrid superplastic forming is a sheet forming technique that combines a hot drawing process and a gas forming process. Compared with the conventional superplastic forming process, the thickness distribution of AZ31B part formed by hybrid superplastic forming was significantly improved. Additionally, the microstructure evolution of AZ31 was examined by electron backscatter diffraction. Many subgrains with low misorientation angle were observed in the coarse grains during hybrid superplastic forming. Based on the tensile test results, parameters of hyperbolic sine creep law model and two-term material constitutive model were determined at 400 ºC. The hybrid superplastic forming behavior of non-superplastic grade AZ31B was predicted by ABAQUS using these two material forming models. The FEM results of thickness distribution, thinning characteristics and forming height were compared with the experimental results.

#00173

Microstructure and mechanical properties of an ultrafine grained medium-Mn steel

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The developing automobile industry requires novel high-strength steels for the car bodies. The medium-manganese steels exhibiting effects of twinning induced plasticity (TWIP) and transformation induced plasticity (TRIP) demonstrate an excellent combination of high formability, strength and plasticity. These beneficial mechanical properties make these steels the most attractive materials in the segment of advanced automobile materials. The effect of cold working followed by annealing on the development of ultrafine grained microstructure and mechanical properties of an Fe-12%Mn-0.6%C-1.5%Al medium-manganese steel was studied. The steel was cold rolled with intermediate annealings and then annealed at 873 K or 923 K for 30 min. The yield strength and total elongation of the Fe-12Mn-0.6C-1.5Al steel after cold rolling were 1200 MPa and 14%, respectively. The heat treatments resulted in the formation of two phase (austenite-ferrite) ultrafine grained microstructures with average grain sizes of 0.9 to 1.2 μm, depending on the annealing temperature. The annealed ultrafine grained steel samples exhibit the yield strength in the range of 800-950 MPa, the ultimate tensile strength in the range of 1150-1200 MPa, and total elongation of 12% to 19%. The influence of the thermo-mechanical processing on the microstructure, phase content and mechanical properties is discussed.
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Invited #0020

Modeling the effects of grain boundary sliding on texture evolution of superplastic materials by a new viscoplastic self-consistent polycrystal approach

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A recent modeling scheme developed for grain boundary sliding [Zhao et al. Adv. Eng. Mater. 17 (2015) 1748-53] was implemented into the viscoplastic self-consistent polycrystal approach for modeling the effects of grain boundary sliding (GBS) on the evolution of the crystallographic textures of materials deforming in superplasticity. The model considers 12 grain boundaries for each grain and follows their evolution during large strain. Detailed analyses were carried out for fcc, bcc and hcp crystallography for two deformation paths: in tension and in simple shear. It is shown that with increasing GBS the texture strength decreases while the signature of the texture type is kept the same. GBS affects the texture components differently with respect to intensity and angular position. The role of the rigid body rotation is emphasized which produces texture variations in simple shear. The effect of the high strain rate sensitivity is an acceleration of the texture rotation in simple shear while in tension increasing strain rate sensitivity slows down the orientation changes of the grains.

#00175

EBSD study of copper and aluminium deformation twinning under condition of high-speed deformation by dynamic channel angular pressing

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EBSD study of copper microstructure fragmentation under condition of high-speed deformation by dynamic channel angular pressing (DCAP) is presented. It has been shown that extensive deformation twinning occurs during single DCAP pass. A local analysis of the misorientation evolution at individual twin boundaries during plastic deformation was conducted. Based on this analysis, the relationship between the deviation from exact twin misorientation and the strain, at which the twin has been nucleated, is suggested. The deformation twins are shown to appear mostly at a final stage of deformation during the DCAP pass.
An experimental evidence of deformation twinning in coarse-grained aluminium deformed by DCAP is presented using EBSD. Twin-oriented mesobands of 3 to 20 μm in width appear predominantly near grain boundaries. Crystallographic characteristics of the mesobands formed in two different grains were examined in detail. The above mentioned local analysis showed that the first mesoband family could be formed at an early stage of the DCAP pass, while the second family – at a later stage. The mesobands were suggested to form by successive nucleation and coalescence of microscopic twins during the shear localization. Therefore, deformation twinning occurs in polycrystalline aluminium as well as in copper under high strain-rate dynamic deformation, in spite of the fact that aluminium is characterized by high stacking fault energy and high dislocation mobility.

#00179

New approach to evaluate accumulated strains during severe plastic deformation

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During the application of severe plastic deformation (SPD) techniques for producing ultrafine grains in various materials the latter are usually subject to large non-stationary deformations. Nonstationarity of such processes leading to essential change of the strain tensor orientation complicates both the tensor analysis of the material deformation state and definition of the scalar characteristics, namely, the value of accumulated strains.
The report considers new approach to evaluation of the accumulated strains in the samples subjected to SPD. This approach is based on the conception of Joseph Lagrange to study continuum kinematics and a velocity field of particles movement along physical routes in the deformed sample and then determine a true value of accumulated strains.
The calculation of accumulated strains has been made for SPD technique - equal channel angular pressing (ECAP).
The regularity of distribution of total strains and its components depending on the cross-section of the specimen and curvature of its bending in the deformation zone has been established. The shear strain component in each pressing pass, as in the experiment, is distributed almost uniformly in the specimen. The value of rotation strain component increases with the enhancement of the curvature of its bending in the deformation zone and its contribution to the total deformation is approximately twice the contribution of the shear component.
This work suggests the ways of increasing the intensity of strain accumulation and the degree of grain refinement during ECAP by application of combined deformation providing concurrent plastic torsion and shear strain in the narrow deformation zone.

Invited #0093

Superior strength and ductility of ultrafine-grained materials: fundamental issues and latest findings

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Over the last two decades it was well documented that the formation of ultrafine-grained (UFG) structures with the grain sizes in submicron (< 1 micron) or nanometer (< 100 nm) range in metallic materials increases strength but typically also leads to decrease in ductility. However, recent studies demonstrated that extraordinarily high strength and enhanced ductility can be obtained in the UFG metals and alloys when it is possible to control not only grain sizes but also the formation of various nanostructured elements, such as nanoparticles, nanotwins and grain boundary structures (states) by means of severe plastic deformation (SPD) techniques. These new trends applied to different metallic materials with superior strength and high ductility are considered and discussed in the present paper. Special attention is paid to study the influence of grain boundary structure parameters (crystallography, defect structure and segregation of alloying elements) on the ductility of UFG materials. The possibility is shown to considerably enhance the development of grain boundary sliding and provide high ductility even at room temperature by varying these parameters through SPD processing regimes. The report also considers practical application of this new approach.

#00152

Enhancement of the strength and ductility of a Ti alloy processed by HPT

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It is known that the techniques of severe plastic deformation (SPD) enable increasing significantly the strength of metals and alloys by means of grain refinement in the structure down to the nanometer scale. Of special interest, in terms of producing ultrafine-grained (UFG) materials, is the high pressure torsion (HPT) technique, which is implemented using anvils with application of compressive pressure of 3-6 GPa and subsequent rotation of a movable anvil with respect to its axis with a rate of 0.2-1 rev/min. Through the example of many metals and alloys it has been demonstrated that the HPT processing of disk-shaped coarse-grained billets leads to an intense grain structure refinement to the sizes of 100 nm and smaller, and also promotes the formation of predominantly high-angle grain boundaries in combination with a high level of internal stresses. It is known that in the process of HPT the ultimate tensile strength of metal and alloys grows, but there is a problem of a sharp decline in ductility, especially in the case of hard-to-deform alloys. In the present paper, we have demonstrated, through the example of the titanium alloy Ti-6Al-4V, the possibility to produce samples having a high-strength (1740 MPa) and increased ductility by HPT processing at different temperatures. In order to reveal the nature of this effect, we have investigated the features of the alloy's structural state prior to and after deformation.

#00199

Thermomechanical processing as an effective method of preparation of bulk and sheet semifinished products from nickel alloys with UFG and NC structures

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This paper presents a systematic study of the mechanisms of structure formation of a wide range of nickel and nickel-iron based alloys with different types of strengthening in a wide temperature – strain rate interval of plastic deformation. The character of operating mechanisms of plastic deformation and recrystallization, and their correlation with processes of dissolution and precipitation of second phases were analyzed.
Regimes of thermomechanical processing that provide stage-by-stage transformation of a coarse-grain structure into a ultrafine-grained (UFG) one, and further to nanocrystalline (NC) structural state, were established. The effect exerted by the morphology of strengthening phase and processing conditions on the development of structure formation during hot, warm and cold deformation were revealed. The obtained data have formed the basis for the development of a general methodological approach to the production of bulk and sheet semi-finished products from UFG and NC nickel based alloys. The correlation between the phase composition and the type of strengthening of superalloys with thermal stability of UFG and NC structures, and the possibility of manifestation of the effects of low temperature and high strain rate superplasticity have been revealed.
There was proposed a method of molding under superplastic conditions which allows producing precise complex geometry parts such as aircraft engine disks from the UFG workpieces with a structure regulated by varying along the radius, which provides a high complex of properties, optimized to the actual conditions of their use.

#0088

Mechanical behavior of Ti-6Al-2Sn-4Zr-2Mo titanium alloy under hot and superplastic forming conditions: experiment and modeling

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Titanium alloys are widely used in the aircraft industry. Under sheets form, they can be employed to the manufacturing of pylon or engine parts. With the aim of a cost reduction, this study proposes to act on the starting microstructure so as to improve the mechanical properties during the forming stages. In order to ensure this, the microstructural evolution and the deformation mechanisms acting on the mechanical behavior will be identified for a large amount of test conditions, more important than those considered from an industrial point of view.
In the present study, investigations are focused on Ti-6Al-2Sn-4Zr-2Mo (Ti6242) alloy specially used for the hot areas (e.g. parts close to the engine or the combustion chamber …). In such conditions, this alloy provides better mechanical properties than Ti-6Al-4V alloy. Presently, an important mechanical test campaign was performed on Ti6242 alloy, it examines, on the one hand, the microstructure qualified by the aircraft industry and, on the other hand, a new range of refined microstructures obtained by hot straining process. For each test, microstructural observations exhibited complex phenomena including simultaneously both grain growth and dynamic recrystallization. The occurrence, sequencing and coupling of the mechanisms, strongly dependent on the starting microstructure and the test conditions (time-temperature and strain rate) investigated. They are not easy to understand and require further tests and observations. In such a framework, the implementation of mechanical models are efficient and relevant to promote a better knowledge of the microstructural evolution observed and their influence on the mechanical behavior.

#00185

Superplasticity in fine grain Ti-6Al-4V alloy: mechanical behaviour and microstructural evolution

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Superplastic forming (SPF) is an expensive process requiring high temperatures and low strain rates. Several studies deal with the decrease of its cost by improving the formability of materials at lower temperature, in particular, using refined microstructure. Titanium Ti-6Al-4V alloys are known to exhibit interesting superplastic properties. Moreover different deformation and accommodation mechanisms might be involved during SPF depending on the grain size, the temperature, the strain rate and, for the Ti-6Al-4V, on the phase fraction (alpha/beta).
This study focuses on the mechanical behaviour and the microstructural evolution for a wide range of temperature (750°C-920°C) and strain rates (10^{-2} s^{-1}-10^{-4} s^{-1}) of a fine grain Ti-6Al-4V (d_{alpha} = 3 micrometer). For the lowest temperature, results are compared with an ultrafine grain Ti-6Al-4V alloy (d_{alpha} = 0,5 micrometer). Additional static tests with different temperature exposure times similar to tensile tests duration were done to investigate the “static” and “dynamic” grain growth. To study more precisely the microstructural evolution, interrupted tensile tests were conducted. SEM observations with image analyses allow the study of the evolution of grain size with the temperature and deformation. Under 920°C, the obtained grain growth can be related to the slight hardening observed on stress-strain curves. The phase fraction evolution versus the temperature was also assessed and confirmed that for temperatures within the range of 850°C-920°C the beta phase may have a contribution on superplasticity. These data associated with XRD and EBSD analyses allow discussion of the two phase’s texture evolution and accommodation mechanisms during high temperature straining.

#00188

Influence of the Initial Structure of High-Strength Titanium Alloys on the Properties of Superplasticity.

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Of high strength titanium alloys manufactured a large range of products, including dimensional stamping and forging. The possibility of applying the method of isothermal forging in the mode of superplastic forming the material would increase manufacturability, reduce machining value and to increase the yield.
Near beta alloys have very high strength to temperatures of 300-450°C, but rapidly lose strength with increasing temperature. The temperature of polymorphic transformation (Tβ) of these alloys does not exceed 850°C. The SPD in these alloys is observed in the two-phase zone, i.e. at a temperature below 850°C, which allows to reduce losses on the oxidation of material and equipment, and use less expensive materials for fabrication of tooling.
In this work the results of the influense of the initial state of the material alloys VST55531, VST3553, VT16 on the plasticity during deformation in superplastic mode.
The analysis of the microstructure of the alloys in the original heat treated condition and after superplastic deformation. Considered changing the structure after deformation. Certification of structure bars performed by the method of diffraction of backscattered electrons (EBSD).

#0035

Plastic Flow Machining

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The new Plastic Flow Machining (PFM) process is presented. It was invented and patented in Metz, France, 2015, by three of the present authors [Patent: FR1557031, 2015, Universite de Lorraine (France) Y. Beygelzimer, L.S. Toth, J.-J. Fundenberger]. The PFM process is a separation of a thin surface layer from a billet. The key point is that the separation occurs by large plastic deformation under compressive stresses. This allows one to obtain sheets, strips, plates and roads with ultrafine-grained gradient structures. In the present paper, the PFM process was studied in three ways: (i) by experiments, (ii) by an analytical model based on the energy principles of the theory of plasticity; (iii) by the finite element method (using the DEFORM software). The results show that PFM is capable of producing metal sheets with ultrafine-grained gradient structures thanks to simple shear deformation and with excellent mechanical properties.

#003

Orientation dependence of mechanical behavior of FCC $CoCrFeNiAl_{0.3}$ high-entropy alloy single crystals

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Tensile deformation behavior and deformation mechanisms (slip and twinning) in single crystals of $CoCrFeNiAl_{0.3}$ high entropy alloy (HEA), with stacking fault energy 0.05 J/m^2, were studied along three different crystallographic orientations, i.e. [001], [011], $[\bar{1}11]$at tensile strain in a wide temperature range T = 77-423 K. It is established that the critical resolved shear stresses under tensile strain of $CoCrFeNiAl_{0.3}$ HEA single crystals are independent of crystal orientation and the Schmid law is satisfied. It was shown that in the temperature range 77-423 K a planar dislocation structure with dislocation pile-ups is observed, which provides evidence for the suppression of the cross-slip in these three studied orientations of $CoCrFeNiAl_{0.3}$ HEA. Twinning in $CoCrFeNiAl_{0.3}$ HEA crystals was observed in $[\bar{1}11]$and [011] orientations at the temperature of liquid nitrogen after strain of 15-20%, which develops in two and one system, respectively. The development of twinning simultaneously with slip in $[\bar{1}11]$and [011] crystals leads to an increase in the strain hardening coefficient and an increase in the stresses for neck formation compared to deformation only by slip at the same test temperature in [001] crystals.
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Invited #0049

Research on Quick Superplastic Forming Technology of Aluminum Alloy Complex Components

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Quick superplastic forming is a new technology, which combines hot drawing preforming and superplastic forming. It makes full use of the high speed of hot drawing and good formability of superplasticity. This article uses this method to have an experiment of the side wall outer panel of metro vehicle. The results show that the production efficiency is high, the cost is low and the method is feasible. For aluminum alloy complex components, it can solve the difficulties of stamping and low speed of superplasticity. The best process which combines hot drawing and superplastic forming was determined though this research. The high-speed rail edge skin with a very small fillet shape (R≤4mm) and the large-size subway door frame part (h≈80mm) formed by straight wall deep drawing were manufactured, using industrial aluminum alloy sheet with thickness of 4mm. The formed parts show the advantages of high dimensional accuracy and uniform wall thickness distribution. The reduction of wall thickness decreased from 56% of traditional superplastic forming to 34% of quick superplastic forming. Meanwhile, the mechanical properties of formed parts can completely meet the requirements.

#0018

Influence of longitudinal interface defect on high cycle fatigue behavior of Ti-6Al-4V alloy Diffusion Bonding joint

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Joints of Ti-6Al-4V alloy with non-defect、Φ2mm diameter、Φ4mm diameter and penetrating defect were artificially fabricated by Diffusion Bonding process. The effects of interface defects on high cycle properties of Bonding joints are quantificationally investigated based on fatigue experiments (R=-1) while the defect plane is parallel to the load axis. Results indicate that the high cycle fatigue limit of joints with non-defect and Φ2mm diameter have simultaneously reached to 420MPa, while HCF limit of joints with penetrating defect alloy has fallen to 310MPa. Compared with other defect couples, joints with Φ4mm DB defect shows a larger scatter of life that HCF strength doesn't converge. Meanwhile defects have influenced on fatigue initiation location that fatigue crack of couples with non-defect mainly initiate from out-surface and fatigue crack of couples with penetrating defect mainly initiate from sub-surface. Fatigue samples with Φ4mm diameter defect initiated surface exhibited longer fatigue life; while almost all samples with defect-induced crack initiation exhibited a much shorter fatigue life.

#0024

Severe plastic deformation of a metastable beta titanium alloy: Grain refinement and phase transformation

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Severe plastic deformation (SPD) by high pressure torsion (HPT) and shear punching (SP), respectively, was performed on a metastable beta titanium alloy. Nano beta grains of < 50 nm were achieved at moderately high strains and relatively low strain rates. The effective grain refinement was attributed to the formation of the stress induced α" martensitic plates which divided beta grains into smaller domains and enabled subgrains to form even in very fine grains. Further deformation led to a reverse α" to β transformation which would occur when the thickness of the α" laths reached < 10 nm, leading to a pure nanocrystalline beta grain structure. Theoretical analysis revealed that extremely high energies required for the formation of α" in nano-sized beta grains made further martensitic transformation impossible. The uniform nanocrystalline grain structure was, however, destroyed by SP at relatively high strain rates. Aging at 600 °C of the HPT processed alloy resulted in equiaxed alpha precipitation, compared to the lamellar morphology usually formed during ageing of such alloys. Extensive electron microcopy revealed the steps through which the equiaxed alpha formed.

#0081

Establishment of the High Temperature Constitutive Relationship of the Haynes230 Ni-based Superalloy

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The high temperature flow behavior of materials is an important basis to study their formability and to determine reasonable forming process parameters. In this work, the high temperature plane strain compression tests were employed to reveal the high temperature flow behavior of Haynes230 Ni-based superalloy under the wide range of temperatures (950℃-1200℃) and strain rates (0.01/s-10/s). The stress-strain data from the tests were applied to model the strain-compensated Arrhenius physically-based constitutive equation and considering the dynamic recovery (DRV) and dynamic recrystallization (DRX) phenomenological constitutive equation. The comparison indicated that the predictions of the two modeled constitutive equations are in good agreement with the experimental data. The prediction of the flow behavior of Haynes230 Ni-based superalloy of strain-compensated Arrhenius constitutive equation is more accurately (average absolute relative error (AARE) is 2.84%) than that of considering DRV and DRX constitutive equation (AARE is 7.57%).

#0085

Influence of oblique edge blanking on the online punching quality after stretch bending

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For surrounding sag falures of the material induced by the uncontrollable clearance between blank and die during the online punching after stretch bending, oblique edge punches are adopted in the blanking of stretch bending parts. The finite element model of oblique edge blanking is established by using the DEFORM software. The optimal height of the edge of the unilateral bevelled punch and the single-peak bevelled punch are determined by analyzing the magnitude of the blanking force, the wear and tear of the punch, and the depth of the surrounding sag of punching. Influence of several oblique edge punches and the positions of the oblique edge, height of the edge on surrounding sag quantity are explored. The test oblique edge punchs are designed, and the experiments of the online punching process of a certain automobile door frame are carried out. The results show that the depth of the surrounding sag of punching can be reduced, and the appearance quality can be improved by the oblique edge blanking; optimal height of the edge of the unilateral bevelled punch equals to 40%-60% of the thickness of the material; the optimal height of the edge of the single-peak bevelled punch equals to 60% of the thickness of the material; when installing a punch, the tip of the edge should be placed near the side with higher quality requirements so as to improve the appearance quality; effect of the unilateral bevelled punch on alleviating the sag is better than that of the single-peak bevelled punch, while the wear of the former is more serious.

#0080

Research on solution treatment process of Haynes230 cylindrical blank used for hot flow spinning

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Crack easily occurs when using the cylindrical blanks obtained from the forging billet after the wire-electrode cutting during hot flow spinning of Haynes 230 alloy due to the severe segregation of carbides exists in the microstructure of the Haynes230 forging billet. The segregation of carbides can be eliminated by solution treatment. Therefore, the solution treatment of Haynes230 cylindrical blanks used for the hot flow spinning process was researched to eliminate the severe segregation of carbides and to obtain the homogeneous microstructure; and the influence of solution treatment process on the microstructure and hardness of Haynes 230 cylindrical blank was also researched. Results show that the grain size increases and the hardness decreases after solution treatment. The severe segregation of carbides is eliminated after solution treatment at 1230℃ for 60 min heat preservation. Whereas, at the temperature of 1260℃, slight over-burning phenomenon occurs in the microstructure of Haynes230 alloy during solution treatment. Conclusions can be drawn from the research: (1) The severe segregation of carbides can be eliminated and the cylindrical blank with homogeneous microstructure used for hot flow spinning of Haynes230 alloy can be obtained after solution treatment at 1230℃ for 60 min heat preservation; (2) The grain size of Haynes230 alloy increases with the increasing of solution temperature and the holding time; the hardness of Haynes230 alloy decreases with the increasing of solution temperature, but negligibly changes with the holding time; (3) The abnormal growth of grains occurs with excessive solution temperature and holding time, which is not beneficial for improving the plasticity of Haynes230 alloy.

#00150

On Strengthening of a High-Mn TWIP Steel by Cold Working and Subsequent Annealing

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Recently, new approaches to simultaneous enhancement of both strength and ductility have aroused great interest among materials scientists. These approaches involve the development of bimodal, hierarchical grain structures consisting of relatively coarse grains embedded inside a matrix of ultrafine grains. However, practical applications of various strengthening methods to produce high-Mn steels with improved mechanical properties require more systematic studies on the effects of processing conditions on microstructures and properties as well as the structure–property relationships in these steels. The microstructure and mechanical properties were studied in an Fe-17Mn-1.5Al-0.3C TWIP steel processed by cold rolling to various total strains from 0.2 to 3.0 with subsequent annealing at temperatures from 823 to 1073 for various periods of time. The steel with partially recrystallized microstructure exhibited the yield strength and total elongation above 600 MPa and 30%, respectively. The same level of strength along with total elongation above 60% was achieved by the development of a uniform fine-grained recrystallized microstructure with a grain size below 1 μm in the sample subjected to cold rolling to a strain of 3 followed by an annealing at 873 K for 1 h. The influence of the initial cold rolling strain on the hardness after cold rolling and on the recrystallized fraction were formulated using power law relationships, whereas the yield strength after annealing was found to be predictable by consideration of dislocation density in non-recrystallized grains and size of recrystallized grains.

#009

Enhanced mechanical properties of asymmetric cryorolled copper sheets under low-temperature annealing

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Bulk UFG/NG materials, have excellent performances such as high strength, high fatigue service life and extreme creep resistance, which have been attracting a great deal of attention during recent years. Bulk fabrication of metallic sheets using the severe plastic deformation technique such as accumulative roll bonding, asymmetric rolling, cryorolling and asymmetric cryorolling has probably brought us closer to enabling a use of UFG materials for structural and functional applications. For AR, additional shear strain contributes to grain rotation and subdivision, producing grain refinement and modification of crystallographic texture, which also can manufacture products with thinner thickness. For CR, the suppression of dynamic recovery during deformation at extremely low temperatures (cooled by liquid nitrogen) preserves a high density of dislocations generated by deformation. ACR is a technique combined the features of AR and CR.
In this paper, copper sheets were processed by asymmetric rolling and asymmetric cryorolling with rolling speed ratio of 1.3 respectively, and then they were annealed at 100ºC for 1 h. The mechanical properties and microstructures of the sheets were analysed by tensile test, transmission electron microscopy (TEM), etc. Results show that the sheets fabricated by asymmetric cryorolling has high strength compared to that by asymmetric rolling. In addition, the low-temperature annealing results in the improved strength and ductility for asymmetric cryorolled copper sheets, while the strength was reduced for asymmetric rolled copper sheets. TEM images show that the thermal stability of the sheets by asymmetric cryorolling is better than that by asymmetric rolling. Finally, we focused on discussion of the mechanisms for improved mechanical properties of asymmetric cryorolled sheets such as changes in grain boundary, slightly recrystallization and twins during annealing.

#0036

Study on hot tensile behaviors of aluminum alloy sheet AA2219

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The hot deformation behaviors of materials are essential for the precise numerical simulation of hot sheet forming processes. This study is carried out to provide detailed hot deformation information on aluminum alloy sheet AA2219-O with 30mm thickness. The hot deformation behaviors of the AA2219-O are studied by uniaxial tensile tests at the temperature range of 415-515°C and stain rate range of 0.001-0.1s^{-1}. The effects of temperature and strain rate on the hot tensile behaviors are discussed in detail. The results show that under the tested deformation conditions, the flow stress decreases with the increase of deformation temperature or the decrease of strain rate. Additionally, the elongations at fracture under the stain rate of 0.001 s^{-1} are all greater than 60% in this study.

#0033

Microstructure and strength properties of ultrafine-grained Cu-10% Zn alloy obtained by equal-channel angular pressing

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It is known that stacking fault energy (SFE) significantly affects the processes of the microstructure refinement, and the strength of materials. This effect was established, in particular, for materials with ultrafine-grained (UFG) structure obtained as a result of severe plastic deformation (SPD), for example, the Cu-Zn, Cu-Al alloys. However, these investigations were performed on samples subjected to SPD by high pressure torsion and having small dimensions, which limits their practical applications. SPD, realized by equal-channel angular pressing (ECAP), allows to obtain bulk UFG samples, which are of practical interest. Analysis of the literature showed that the investigations of the role of SFE on the processes of the microstructure refinement and strength are very limited numbers and further detailed investigation is required.
In this paper we report a microstructure and strength properties investigations of a Cu - 10 mass. % Zn alloy subjected to ECAP, with the aim of forming a UFG structure and enhancing the strength properties. The obtained results for this alloy having an average SFE value (35 mJ m^{-2}) are compared with the results obtained for pure UFG copper with a high SFE value equal to 78 mJ m^{-2}. It is shown that the decrease in SFE value leads to more developed microstructure refinement, an increase in the density of dislocations and twins, which, in turn, provides an increase in strength characteristics.

#00143

The effect of finite element geometry on superplastic forming simulation

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One of the most popular approaches to the design of superplastic forming technologies is the numerical simulation utilizing finite element method with shell three-dimensional elements. This approach is based on the membrane theory neglecting shear strains which appear in the zones of contact between the forming specimen and the die. The objective of this paper is to study how the type of an element effects on the simulation results. Two approaches to the superplastic forming process simulation were considered in the work. In the first one the axisymmetric simulations with rectangular finite elements were carried out. The three-dimensional simulations with four-node plane finite elements were performed in the second case. Different material properties, die geometry and the initial thickness of the specimen were considered. Besides, the calculations were performed both with a constant pressure regime and with the one ensuring a constant strain rate at the specimen. The recommendations concerning the shell elements applicability were suggested based on the comparison of two approaches.

#0096

Evaluation of Intensitivity of Plastic Deformation with Acoustic Waves

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Estimation of the intensity of plastic deformation is an independent modern material science problem. It can be successfully solved by analyzing the structural structure of materials, calculating the values of their physical characteristics, which in turn are related to the dynamics of the processes of nucleation and development of individual defects or their systems. As shown in the course of the experiments, the tasks, as well as the problem of predicting the critical state of materials, are solved using methods based on the use of acoustic waves, primarily the GHz range. They make it possible to obtain, with the aid of acoustic waves, subsurface acoustic images of the structure of materials, to observe its transformation during the deformation process. On the basis of the beam approach, a method is developed for calculating the velocities of acoustic waves and the level of their attenuation from characteristic V(Z)-curves in the samples. The methods ensure the calculation of elastic modulus and their changes as a result of external influences, the identification and characterization of defective structures, analysis of the relationship between the grain size and the speed of acoustic waves.
The transformation of the acoustic contrast of images of regions with different symmetry parameters was experimentally observed. Acoustic microphotographs of textures in steels were obtained, the deviation of the mean value of the SAW velocity in steels during measurements along the strain axis in the V (Z) -curve regime was observed.

#00157

Microstructural evolution during friction-stir welding of Al-Mg-Sc alloy

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Microstructural evolution during friction stir welding of Al-Mg-Mn-Sc-Zr alloy with initial grain size of ~ 20 µm was studied. The grain development process was shown to be dominated by continuous recrystallization. The microstructure evolved in stir zone was characterized by relatively fine grain size (~1.3 µm), large proportion of high-angle boundaries (~90%) and weak simple-shear texture. All these effects were attributed to the complex character of slip associated with second-phase particles.

Invited #00140

Low-temperature superplastic deformation of ultrafine Ti-6Al-4V

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Microstructure evolution and mechanical behavior of ultrafine Ti-6Al-4V during the low-temperature superplasticity was studied. An ultrafine microstructure with a mean size of α (sub)grains and β particles of 0.1-0.4 μm was produced using warm multiaxial forging. The static and dynamic coarsening response and plastic-flow behavior were determined via a series of tension tests at temperatures between 450 and 700°C. and strain rates of 10^{-5-} to 10^{-3} s^{-1}. Both static and dynamic coarsening exhibited diffusion-controlled (r^3-vs-time) kinetics. However, dynamic coarsening was approximately two orders of magnitude faster than the corresponding static behaviors due to enhanced diffusion through the deformed β matrix. A total elongation of 1000% and strain-rate-sensitivity exponent m = 0.48 were obtained at 550°C and 2×10^{-4} s^{-1}. Very limited cavitation was observed in the specimens after superplastic deformation under optimal conditions. The very high mechanical properties, limited cavitation, and the large difference in static vs dynamic microstructural coarsening of the ultrafine alloy at 550°C can be associated with the redistribution of the β phase from triple-junction locations to the matrix during SP deformation.

Invited #0084

Influence of Inhomogeneity on Mechanical Properties of Commercially Pure Titanium Processed by HPT

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Already for fifteen years many researchers have been trying to discover metallic materials with unusual combinations of strength and ductility: with high strength and enhanced ductility. This combination may be achieved through different ways: alloying, nanostructuring, etc. This report is an attempt to analyze the influence of inhomogeneity of different types (structural, phase and space) on mechanical properties of commercially pure titanium (bulk and powder) subjected to high-pressure torsion. Experimental results for HPT bulk and powder titanium have demonstrated that mechanical behavior of CP titanium strongly depends on phase inhomogeneity (alpha + omega phases), structural inhomogeneity (bimodal grain size distribution) and space inhomogeneity (retained porosity) in case of cold consolidated Ti powder. High strength in HPT bulk titanium due to a formation of hard omega phase during HPT processing at room temperature was detected. The strong omega phase transforms back to nanograined alpha phase domains during short annealing at elevated temperature. HPT consolidation of titanium powder leads to creation of brittle specimens showing high strength but almost zero plasticity.

Evolution of misorientations at deformation-induced high-angle boundaries during plastic deformation of metals

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When studying grain refinement by crystal lattice fragmentation under developed plastic deformation, it is of great importance to characterize evolution of high angle deformation-induced boundaries (DIBs) as long as their creation and evolution controls the refinement. A problem appears, however, to separate the contribution of DIBs to the overall misorientation distribution from the contribution of original grain boundaries, more particularly at mediate strains about 1 to 3, when total lengths of the high-angle DIBs and the original boundaries are comparable. In the present report, an EBSD-based method making possible this separation is suggested and shown to provide reasonable accuracy. Using this method, the evolution of DIB misorientations is characterized in polycrystalline copper and iron deformed by uniaxial compression, 2D forging and dynamic channel angular pressing.

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