Forum I High Performance Metallic Materials

I01 (Invited)

Revisiting to the Hardening Precipitates in High Strength Aluminum Alloys by State-of-the-art Electron Microscopy

J. H. Chen

Center for High-Resolution Electron Microscopy, College of Materials Science and Engineering, Hunan University, Changsha, Hunan 410082, China

Developments of high-strength aluminum alloys have always faced a difficult problem: owing to their small size, the early-stage strengthening precipitates are difficult to characterize in terms of composition, structure and evolution. Here we employ atomic-resolution transmission electron microscopy (TEM) imaging and first-principles energy calculations to address these problems. Recent years, we have investigated tens of typical high strength aluminum alloys, such as 2xxx (AlCu, AlCuMg and AlCuLiMg), 6xxx (AlMgSi and AlMgSiCu) and 7xxx (AlZnMg and AlZnMgCu) alloys, with different compositions and with varying thermal processes for understanding their property-structure-process correlations. Using aberration-corrected high-resolution TEM (HRTEM) and aberration-corrected scanning TEM (STEM), much of our attention has been paid to revisit the strengthening precipitates in these important alloys and to clarify the controversies left in the past about their precipitation behaviors. Our study demonstrates the followings:

(1) Atomic-resolution imaging in STEM can provide straightforward structure models at the atomic-scale, whereas atomic-resolution imaging in HRTEM with rapid quantitative image simulation analysis can provide the refined structures with high precision beyond the resolution limitation of the microscope. The combination of the two techniques can be more powerful in solving difficult structure problems in materials science.

(2) Most of the early-stage precipitates in aluminum alloys are highly dynamic in both composition and structure. Typically, having their characteristic genetic skeletons to guide their evolution, these dynamic precipitates initiate, mature and grow with thermal aging following characteristic evolution paths. The fine precipitation scenarios revealed in our studies are rather different from previous understandings in the textbooks and literatures published thus far.

I02 (Invited)

The Stress-induced Orienting Effect of Precipitates in Al-Cu-(Mg) Alloys During Creep Age Forming

Professor Yunlai Deng; Doctor Xiaobin Guo; Juan Wang; Cai Hu

School of Materials Science and Engineering,Central South University,Changsha 410083,China

Age forming is a combined age strengthening process with the forming of metals. In stress-aged aluminum alloys, fine precipitates disperse in the matrix but coarse precipitates form on the grain boundary, so the strength and corrosion resistance of alloys are improved compared with conventional cold-forming process. But in some 2XXX series aluminum alloys, application of a stress during aging can significantly affect the orientation of precipitates, namely the stress-orienting effect, which leads to anisotropy of strength properties. This stress-orienting effect directly restricts the development of “age-forming” technique in manufacturing progress of 2XXX aircraft structures. In the investigation, a model based on crystallographic orientation was established to describe the precipitation strengthening of stress-aged Al–2Cu alloy. In the investigation on Al-Cu-Mg single crystal during stress-aging, we found that the stress-induced preferential orientation of S’ precipitates is restrained owing to the dislocations produced by a higher stress. The effect of dislocations on the oriented precipitates depends on the total length of the intersection lines for precipitate habit planes and dislocation glide planes. Investigations on Al-Cu-(Mg) alloy bicrystal showed that grain boundaries inhibite the stress-induced orienting effect of precipitates.

I03 (Invited)

Micro-forming Process in Ultrafine-grained Materials Processed by Severeplastic Deformation

Jie Xu[1,2*],Debin Shan[1,2], Bin Guo[1,2]

[1]Key Laboratory of Micro-systems and Micro-structures Manufacturing of Ministry of Education, Harbin Institute of Technology, Harbin, 150080, China

[2]School of Materials Science and Engineering, Harbin Institute of Technology, Harbin, 150001, China

Grain size appears to be the dominant factor which determines the limiting size of the geometrical features that may be fabricated by micro-forming due and this means that very small grain sizes, and especially materials having ultrafine grain sizes, are attractive for use in micro-forming operations. In this study, ultrafine-grained (UFG) materials including pure aluminum and magnesium alloywere produced by severe plastic deformation (SPD).

Micro-deformation behavior was investigated by micro-compression tests and the results show that ultrafine grains can obviously improve the non-uniform deformation.The formability of UFG materials was evaluated by measuring the percentage of material flowing into the V-groove. The results show that refinement of grain size can significantly improve the formability by increasing the stain rate sensitivity by comparison with the coarse-grained materials. Micro-embossing tests were investigated and micro-array channels with high dimensional accuracy and surface quality were successfully fabricated by micro-embossing processing using a silicon die. These results demonstrate that the UFG materials exhibit excellent formability for fabricating micro-electro-mechanical system (MEMS) components with complicated structures.

Key words: micro-forming, size effect, ultrafine grains, formability, micro-embossing.

I04

Metallic Glass Composite with Good Tensile Ductility, High Strength and Large Elastic Strain Limit

Fu-Fa Wu*

Liaoning University of Technology, School of Materials Science and Engineering,

People's Republic of China

Bulk metallic glasses exhibit high strength and large elastic strain limit but have no tensile ductility.However, bulk metallic glass composites reinforced by in-situ dendrites possess significantly improved toughness but at the expense of high strength and large elastic strain limit. Here, we report a bulk metallic glass composite with strong strain-hardening capability and large elastic strain limit. It was found that, by plastic predeformation, the bulk metallic glass composite can exhibit both a large elastic strain limit and high strength under tension. These unique elastic mechanical properties are attributed to the reversible B2-B19' phase transformation and the plastic-predeformation-induced complicated stress state in the metallic glass matrix and the second phase. These findings are significant for the design and application of bulk metallic glass composites with excellent mechanical properties.

I05

Effect of Al Thin Film on Microstructure and Mechanical Properties of Diffusion-bonded Ti/Al Film/Al Joints

Guoqiang Luo[1, a], Jiayu He[2,b], Jian Zhang，Xueshu Hu(Corresponding author)，

Qiang Shen[3,c], Lianmeng Zhang[4,d]

State Key Laboratory of Advanced Technology for Materials Synthesis and Processing, Wuhan University of Technology, Wuhan 430070, PR China

E-mail addresses: [a] luogq@whut.edu.cn, [b] wuthejiayu@163.com

Ti/Al joints have wide applications in many industrial areas such as aerospace, nuclear and chemical industries. In the present study, Ti alloy and Al alloy with and without aluminum thin film were bonded successfully by means of diffusion bonding under low temperature of 380°C. The microstructure and mechanical properties of the joints were investigated. The interfacial structure of the joints was studied by SEM, EDS and XRD. The results showed that the shear strength of Ti/Al film/Al joints was 66.5 MPa which was 2.5 times larger than that of the Ti/Al joints'. The different atoms diffused to each other in the bonding process and no intermetallic compound appeared. The fracture of the joint had taken place in the Al/Al film rather than in the Ti/Al film and the fracture way of the joints was ductile fracture.

I06 (Invited)

Texture Weakening of Mg Alloy Sheets

Bin Jiang, Junjie He, Guangsheng Huang, Fusheng Pan

National Engineering Research Center for Magnesium Alloys,College of Materials Science and Engineering, Chongqing University, China

Advanced Materials Center, Chongqing Academy of Science and Technology, Chongqing, China

Mg-3Al-1Zn alloy with 3 wt.% Li addition was extruded and its mechanical properties were examined.Otherwise than the typical strong basal texture obtained by ordinary Mge3AleZn extruded sheet, theMge3Lie3AleZn alloy showed a non-basal texture with its polar axis partial to the transverse directioncompletely. However, this type of texture would lead to strong planar anisotropy and did harm to thesecondary metalworking. A simple but effective process named presetting grain re-orientation wascarried out to improve the anisotropy of the Mge3Lie3AleZn alloy sheet by introducing specific twins.The work hardening behavior of the initial sheet was deeply analyzed and it was used to guide the predeformationprocess. The research found that the macroscopic selection of the potential twinning planescan be feedback through the strain hardening curve. In addition, the variety and quantity of the introducedtwins were confirmed to play an important role on the texture modification and propertyimprovement of the

Mge3Lie3AleZn alloy sheet during the subsequent recrystallization annealing. Themicrostructure, texture, recrystallization and mechanical properties of various treated samples atdifferent stages were also investigated in detail.

I07 (Invited)

Effects of Er/Sr/Cu Additions on the Microstructure and Mechanical Properties of Al-Mg Alloy During Hot Extrusion

Hongmei Che[1], Xianquan Jiang[1,2], Nan Qiao[1], Xiaokui Liu[1]

[1] Faculty of Materials and Energy, Southwest University, Chongqing 400715, China

[2] Chongqing Research Center for Advanced Materials, Chongqing Academy of Science and Technology, Chongqing 401123, China

The effects of Er/Sr/Cu additions on the microstructure and mechanical properties of Al-Mg alloy during hot extrusion were studied by using metalloscope, scanning electron microscopy, stretcher, hardness tester, linear intercept method and equivalent area method in this paper. Experimental results show that, after hot extrusion, the secondary phases in the whole alloys have been broken into fine particles along the extrusion direction. All of the alloys are composed of fine recrystallized grains except the Al-Mg alloy with addition of Er. Additions of Er, Sr and Cu can refine the grain size and improve the distribution homogeneity of the grains and increase the yield strength, elongation to failure and hardness of Al-Mg alloy. The hardness distribution tendency along the direction which is perpendicular to the longitudinal section of all the alloys are V-shape except Al-Mg alloy with addition of Er, presenting a W-shape.

Key Words: Microstructure; Aluminum alloy; Hot extrusion; Recrystallization.

I08 (Invited)

Atomistic Interface Design of Metallic Nanocomposites

R. F. Zhang [1,*], T. C. Germann[2] and I. J. Beyerlein [2]

[1] School of Materials Science and Engineering and International Research Institute for Multidisciplinary Science, Beihang University, Beijing 100191, P. R. China

[2] Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM, 87545, USA

[*] presenting author, email address: zrf@buaa.edu.cn

Keywords: interface, MD simulation, metallic nanocomposites, plasticity, dislocation

The interfaces in metallic nanocomposites play a critical role in determining their

mechanical behavior under severe plastic deformation and shock loadings. Taken fcc/bcc bimetal interfaces as prototype, we underlined the mechanism of nucleation and dissociation of dislocations at various semicoherent interfaces. By means of quasi-static loading scheme and large scale atomistic simulations, we clarified that the interface types and size effects governs the fundamental mechanical behavior and deformation mechanism of the experimentally observed interfaces. The dislocation slip systems emitted and transmitted across the interfaces are strongly related to the characteristics of interface defects and the geometrical compatibility of pairs of slip systems between neighbor crystals. Our results shed a novel view for the design of high strength and high ductility nanocomposites by the control of interface structures and the nanosized grains/layers.

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I09

Dynamic Recrystallization and Textural Evolution of Zr-1Sn-0.3Nb Alloy with Different Initial Orientation during Hot Compression

Qinghui Zeng, Baifeng Luan*, Wen Zeng, Qing Liu

Email: bfluan@cqu.edu.cn

College of Materials Science and Engineering, Chongqing University, Chongqing, 400044, China

Abstract: In this paper, with a hot-rolled and recrystallized Zr-1Sn-0.3Nb alloy sheet, cylindrical compression specimens with 6 mm in diameter and 6 mm in height were cut from the plate which with their axes (also the compression direction) in the ND-TD plane tilted 0° and 90° to the normal direction (ND) of the parent sheet. Five strain levels (10, 20, 30, 45 and 60%) of uniaxial compression experiments were performed at 700°C with a strain rate of 0.001/s using a Gleeble 1500D thermal simulator. The morphologies, distributions and misorientations of the grain boundaries and texture at different strains were characterized by an electron backscatter diffraction (EBSD) technique and X-ray diffraction (XRD). The EBSD maps indicated that dynamic recrystallization (DRX) occurred during the high-temperature deformation. The processes, namely, grain boundary bulging, strain induced subboundaries around the bulged grain boundaries and their transformation from low misorientation to high misorientation, were considered as the formation mechanism of recrystallized grains. This phenomenon is similar to the rotational recrystallization (RRX) in which the subgrains around original grain boundaries transform into

HABs, partly due to the presence of high local stresses, but not that geometric dynamic recrystallization (GDRX) proposed by Perez-Prado. After 60% compression, the 0° and 90° specimens showed the bimodal basal texture, however the change path of the texture was obviously different.

Key words: Zirconium; Dynamic Recrystallization; Texture; EBSD; XRD

I10

Nucleation and Variant Selection of Massive Phase Transformation in a Zr-Cr-Fe Alloy

Jianmin Wang, Baifeng Luan*, Qing Liu**

College of Materials Science and Engineering, Chongqing University, Chongqing 400044, China

* Corresponding authors. E-mail addresses: bfluan@cqu.edu.cn (Baifeng Luan)

The present study has identified the occurrence of αm massive phasein a Zr-Cr-Fe alloy during rapid cooling from β region.A broad variety of αmmassive grainsdistributing along the prior β grain boundarieshas beencharacterized by electron backscatter diffraction to obtain more insight in the nucleation and variant selection of these massive grains. By comparing crystallographic orientations between αm massive grain and priorβ-grain, it is revealed that these massive grain nucleates always following Burgers orientation relationship (BOR) with one of two adjacent prior β grains boundary (oriented nucleation) and grow into the opposite phase with which there was no specific orientation relationship (non-oriented growth).Furthermore, similar to martensitic transformation, strong variant selectionbehavior also accompany the massive transformation. Degree of variant selectionvarieslargely with different prior β grain boundary.The underlying mechanisms accounting for variant selection are discussed and attributed to the grain boundary energy and interface energy.

Key words: Massive transformation; Zr-Cr-Fe alloy;Burgers orientation relationship; Variant selection; Nucleation;

I11

Effect of Sc, Zr and Ti on Microstructure and Mechanical Properties of Al Alloys

Naiqin Zhao[1, a], Xiaocen Shen[2, b], Jiajun Li[3, c], Chunnian He[4, d], Chunsheng Shi[5, e] and, Enzuo Liu[6, f]

[1]School of Materials Science and Engineering, Tianjin University, Tianjin 300072, China
[2] Tianjin Key Laboratory of Composite and Functional Materials, Tianjin 300072, China
[a]nqzhao@tju.edu.cn, bshenxiaocen@tju.edu.cn

In the present study, the effects of trace amounts of Sc and Zr addition on microstructure and mechanical properties of A356 alloys were investigated. The results show that Sc can reduce the grain size of A356 alloys, leading to the improvement of its mechanical properties, particularly for elongation. In addition, the study indicate that co-addition of Sc and Zr brings in same results as single-addition of same amount of Sc, which can reduce the Sc content in A356. The A356-0.19Sc-0.22Zr has outstanding performances, its EI reach 5.6%, showing a shape improvement compared to elongation (0.7%) of A356.

Keywords: Sc, Zr, Aluminum alloys, Microstructure and Mechanical properties.

I12

Wear Resistance of Spark Plasma Sintered Fe-based Amorphous Coatings

Peng Gu, Jianhua Zhao, Xiulin Ji

College of Mechanical & Electrical Engineering,Hohai University,Changzhou 213022,China

$Fe_{48}Cr_{15}Mo_{14}Y_2C_{15}B_6$ amorphous coating was fabricated Using Spark Plasma Sintering (SPS) technology. Sliding wear mechanism of the amorphous coating was investigated via sliding testing machine and its wear resistance was also compared with AISI 52100 steel. With the increasing of the load, the wear rate of amorphous coating was increased, but the coefficient of friction (COF) was decreased. Amorphous coating has significantly lower wear rate and COF than AISI 52100 steel. The wear surface morphologies show that sliding wear mechanism of amorphous coating mainly is fatigue and adhesive wear. Erosive wear mechanism of this amorphous coating was also investigated via a self-made solid-liquid two-phase-flow erosion tester. At the same time, 1Cr13 stainless steel has been carried out for the comparison and analysis. When the erosive angle increases from 15° to 90°, the weight loss due to erosive wear increases fist and then decreases with the maximum value at 45°. The erosive wear mechanisms are mainly micro-cutting and plowing wear at small impact angle, and distortion of drilling wear and extrusive fatigue fracture at high impact angle. Under different impact angles, weight loss of amorphous coating is larger and the erosive wear resistance is much lower than 1Cr13 stainless steel.

Key word: Amorphous coating; SPS; Sliding wear; Erosive wear; Wear resistance mechanism

I13 (Invited)

First Principlesand Internal Friction Study of Ti-H System

YingyingZong, Cheng Yang, Debin Shan

State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin, Heilongjiang,China

Email:hagongda@hit.edu.cn

Due tohigh activity and small radius, hydrogen is inclined to be in an unstable state when external environmental conditionchanges. So the behavior and role of hydrogen in titanium and titanium alloys is very complex. Recently, microscopic mechanisms between hydrogen and titanium have been proposed according to experimental results. However, the conflicting views exist and the microscopic mechanism of hydrogen-induced plasticity of titanium is lack of theoretical basis.If the phenomena and problems of hydrogen-induced plasticity in titanium cannot be explained and resolved reasonably, the development of thermohydrogen treatment techniquewill be limited. Therefore, further study of the behavior and mechanism of hydrogen in titanium and titanium alloys is necessary. And the simulated calculation and experiments are designed to focus on the nature of elastic deformation and plastic deformation properties in Ti-H system. This paperadopted the first-principles method to study the behavior and mechanism of hydrogen in titanium from electronic and atomic scale.

First principles simulation results show that:hydrogen atoms in α phase and β phase tend to occupy octahedral interstices because hydrogen atoms dissolved in the octahedral interstices release more energy than in the tetrahedralinterstices. Thelattice distortion and volume expansion increases with the increase of solute hydrogen atomsin α-Ti. When the value of solute hydrogen atom exceeds a certain value, the crystal distortion will be too large which leads the crystal structure to convert from hcp to bcc. For the study concerning electronic structure of Ti-H, the new energy of gap has emerged because the electrons in 1s orbit of H atoms interact with that in 3p, 3d and 4s orbit of the nearest Ti atoms. For the α-Ti, the kibbutz number and the electron density of the nearest titanium atom decrease with increasing hydrogen content, so hydrogen would induce the weak bonds in α-Ti. For the β-Ti, the situation is opposite and hydrogen would induce the strong bonds in β-Ti. Meanwhile, for Ti-H system, the bulk modulus is positively correlated with the hydrogen content. Noticeably, the shear and Young's modulus is negative with hydrogen content in α-Ti and positive in β-Ti, as shown in Figure 1.

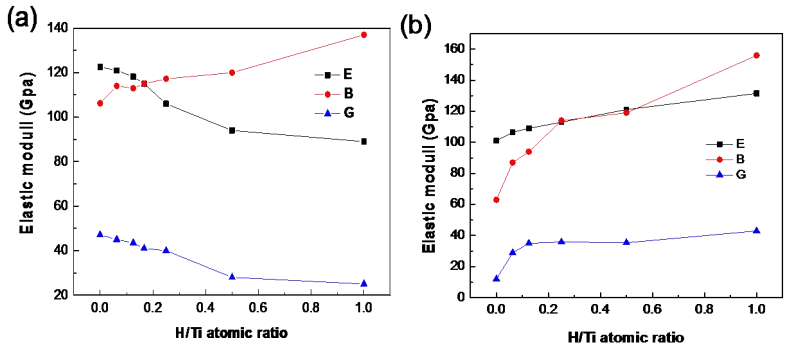

Fig1. Elastic modulus of (a)α-Ti-H system, (b)β-Ti-H system.

Internal friction spectrums of Ti-Hsystemare shown in Figure 2. Internal friction experiments showed that in the high temperature zone the internal friction of recrystallization P0and the relaxation peak Pbof boundary are negative withhydrogen content. It implies that the hydrogenpromotes recovery and suppresses recrystallization. The internal frictions concerning hydrogen with dislocations (P2)and dislocations with point defects (P1) both become more obvious with the increase of hydrogen content, which reveals thathydrogenimproves the movement of dislocations. The internal friction peak P4 caused by solute atoms and dislocationsis negative withhydrogen content, indicating that hydrogen weakened the interaction between dislocations and solute atoms. Snoek internal friction peak is proportional to the hydrogen content because the hydrogen-enhanced diffusion. Elastic modulus has been measured in the α-phase, β-phase and two-phase zone, the experimental resultsconfirm the theory of hydrogen-induced α-Ti weak bonds and hydrogen-induced β-Ti strong bonds, and a mathematical model has been proposed.

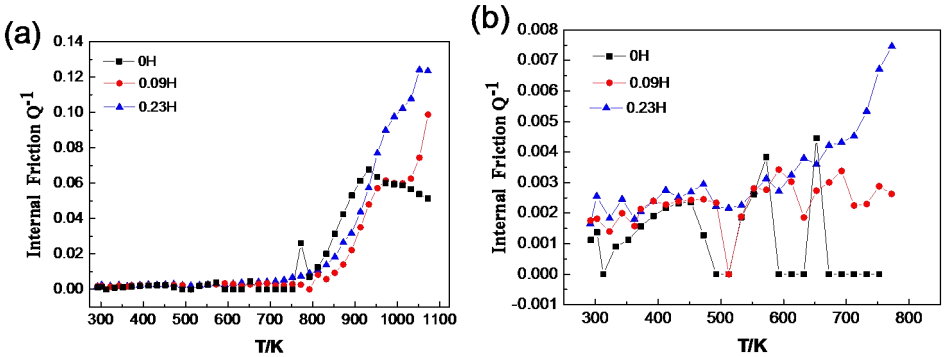

Fig 2.Internal friction spectrum of Ti-Hsystem
(a)Whole spectrum, (b)Low temperature internal friction spectrum.

Current Overview of Nanocrystallization and Amorphization of NiTi Shape Memory Alloy Subjected to Severe Plastic Deformation

Shuyong Jiang

College of Mechanical and Electrical Engineering, Harbin Engineering University

Nickel-Titanium shape memory alloy (NiTi SMA) has been widely used in the engineering field because of shape memory effect and superelasticity. Severe plastic deformation (SPD) contributes to nanocrystallization and amorphization of NiTi SMA, which plays a significant role in enhancing the mechanical properties of NiTi SMA. Many SPD methods, including high pressure torsion (HPT), cold rolling, cold drawing, surface mechanical attrition treatment(SMAT) , local canning compression, are introduced to give a current overview of SPD of NiTi SMA. Based on local canning compression, mechanisms of nanocrystallization and amorphization of NiTi SMA are discussed in terms of multiscales. Crystal plasticity finite element method, cellular automaton, discrete dislocation dynamics and molecular dynamics have been the candidates for revealing mechanisms of nanocrystallization and amorphization of NiTi SMA in the future.

I15 (Invited)

Microstructure Evolution and Mechanical Properties of ZrO_2/TC4 Joints Vacuum Brazed by Ag-Cu Filler Metal

Jian Cao*, Xiangyu Dai, Jicai Feng

State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China

Reliable brazing of ZrO_2 ceramic to TC4 alloy was achieved using inactive AgCu filler metal.The interfacial microstructure of the joints was characterized by scanning electron microscope (SEM), X-ray diffraction (XRD) and transmission electron microscopy (TEM).The effect of brazing temperature on the microstructure and mechanical properties of the joints were investigated in details. The results revealed that Cu_3Ti_3O+TiO layers were formed adjacent to ZrO2 ceramic while Ti–Cu IMCs layers were formed next to TC4 substrate. The TiO-Cu_3Ti_3O bilayer structure had metallic character and hence served as the metallization layers on ZrO_2 ceramic surface.With increasing brazing temperature, the thickness of Cu_3Ti_3O+TiO layers and Ti-Cu IMCs layers increased obviously. The hardness and elastic modulus of reaction phases in the joint were characterized by nano-indentation to reveal the plastic deformability. The highest shear strength of 52.2MPa was achieved when brazed at 870°C for 10 min.The fracture started at the

Cu_3Ti_3O+TiO layers adjacent to ZrO_2 ceramic and then propagated along the Cu_3Ti_3O+TiO layers.

I16

A New Technology for The Preparation of MgB_2 Superconducting Wire

Hong Zhang, Lei Li, Yong Zhao

Key Laboratory of Maglev Train and Maglev Technology of Ministry of Education,

Superconductivity

and New Energy R&D Center, Southwest Jiaotong University, Chengdu 610031, China

It has been more than 100 years since the discovery of superconducting materials, which has entered the application stage from the laboratory research stage. Among the various superconducting materials that can be used in the present, the intermediate temperature superconducting material MgB2 is considered to be one of the most likely to be used in industrial applications, and it is expected to replace the cryogenic superconducting materials. The powder in tube (PIT) method is more mature and practical in the existing preparation technology. Some countries already have the commercial capacity of MgB2 wire prepared by PIT. However, there are many problems in the PIT methods, such as porous, poor grain connectivity, too much impurities, the low critical current density of the PIT prepared MgB2 wire, and so on. Therefore, the preparation technology of MgB2 has a great improvement space. An improved method of the internal center magnesium diffusion (IMD) method is developed in recent years. But this method is in the little sample research stage, and it still presents many problems which need to be improved, for example, the reaction is not completely, micro cracks, and so on. Therefore, in order to improve the IMD method, a new technology for the preparation of MgB2 wire is developed, which is of great significance for the development of domestic intellectual property.

I17 (Invited)

Microstructure and Mechanical Properties of TiAl Alloys Prepared by Cold Crucible Directional Solidification

Ruirun Chen

Harbin Institute of Technology, Harbin 150001, China

Cold crucible directional solidification (CCDS) is a newly developed technique, which combines the advantages of the cold crucible and continuous melting. It can be applied to

directionally solidify reactive, high purity and refractory materials. This paper describes the principle of CCDS and its characteristics; development of the measuring and numerical calculation of the magnetic field, flow field and temperature field in CCDS; and the CCDS of Ti based alloys. In Ti based alloys, Ti6Al4V, TiAl alloys and high Nb-containing TiAl alloys have been directionally solidified in different cold crucibles. The cross-sections of the cold crucibles include round, near rectangular and square with different sizes. Tensile testing results show that the elongation of directionally solidified Ti6Al4V can be improved to 12.7% from as cast 5.4%. The strength and the elongation of the directionally solidified Ti47Al2Cr2Nb and Ti44Al6Nb1.0Cr2.0V are 650 MPa/3% and 602.5 MPa/1.20%, respectively. The ingots after CCDS can be used to prepare turbine or engine blades, and are candidates to replace Ni super-alloy at temperatures of 700 to 900 ºC

I18 (Invited)

A Brief Introduction for the Research Progress and Ability of Vanadium Alloy in Institute of Materials of China Academy of Engineering Physics

Fengsheng Qu

The report shows a brief introduction for the progress of the preparation and processing of vanadium alloys in Institute of Materials of China Academy of Engineering Physics. And it also shows the preparation and processing ability in the vanadium alloys and refractory alloys in Institute of Materials.

I19

The Effect of MgB_4 Doping on MgB_2 Superconductor Prepared by Mg Diffusion Method

Lei Li, Hong Zhang, Yong Zhao

Key Laboratory of Advanced Technology of Materials, Superconductivity and New Energy R&D Center, Southwest JiaoTong University, Chengdu, Sichuan, 610031, China.

The Mg diffusion method with the MgB4 doping is developed to improve the IMD method. A series of MgB4-doped MgB2 bulks with high density have been successfully obtained by Mg diffusion method at 700℃. The precursor powder was uniformly mixed with compositions（1- 4x） mol % of B + x mol % of MgB4 (x = 0, 1, 2, 5, 10 and 20) under pure argon atmosphere. The effects of MgB4 doping on grain size and microstructure morphology of MgB2 have been

investigated. The high-quality MgB2 bulks were achieved with higher density and smaller grains when x was 2 and 5. These results suggest that the Mg diffusion method with a right amount of MgB4 doping could be a good alternative to manufacture MgB2 bulks with excellent performance.