C3. Light Metals and Alloys: Ti and Others I

Symposium Organizers :

Yongqing Zhao, Northwest Institute for Nonferrous Metal Research, China; Yoshihito Kawamura, Kumamoto University, Japan; Young Min Kim, Korea Institute of Materials Science (KIMS), Korea; Jian-Feng Nie, Monash University, Australia; Diran Apelian, Worceste Polytechnic Institute, USA

Tuesday AM — Room: VIP 304 (3rd Floor)
August 20, 2019 — Symposium:C3

Chairs :
Kenichi Mori, Nippon Steel & Sumitomo Metal Corporation, Japan;
Robert Wilson, Commonwealth Scientific and Industrial Research Organization, Australia

8:30-9:00 Keynote（1251733）

Titanium Particulates to Titanium Products

Robert Wilson, CSIRO, Australia

CSIRO is involved in working across the titanium metal value chain, ranging from licensed technologies to synthesize novel titanium metal powders, technologies and strategies to recycle titanium machining swarf to powder for further qualification, developing technologies to make titanium wire and sheet from powder and particulate feeds, and metallic 3D printing/additive manufacturing of titanium components from powder feeds via additive manufacturing methods. An overview will be given defining this value chain and then a specific focus will be given to the recycling of titanium metal machining chips to generate powders for further consolidation. The two powder to product consolidation methods employed by CSIRO are the continuous extrusion particulate to wire (TiWi) and powder to sheet (direct powder rolling/hot roll densification, DPR/HRD) technologies. The output stream for the wires is targeted at wire fed additive manufacturing and wire fed powder atomisation. A description and the current status of the wire and sheet technologies from virgin and recycled powder materials will also be provided. As part of the fabrication of titanium samples by 3D printing, the progress in understanding the processing / microstructure / properties relationship of Laser Engineered Net Shaping (LENS) fabricated Ti-6Al-4V will also be discussed in terms of thermal exposure and microstructures to induce high ductility response.

9:00-9:25 Invited（1253945）

Hot Forging Design for TiAl Alloys based on Dynamic and Metadynamic Recrystallization Investigations

Bin Tang, Lin Xiang, Xiaofei Chen, Hongchao Kou, JInshan Li, Northwestern Polytechnical University, China

The γ-TiAl alloys are considered to be the most important candidate to replace Ni-based superalloys for jet engine. However, the intrinsic brittleness and hard processability of TiAl alloys limit the application. Hot forging is one of the most important approaches to obtain an ingot with fine and uniform microstructure and excellent mechanical performances. In the present work, a multi-direction hot forging route was designed to obtain a fine-grained and uniform microstructure for TiAl alloys based on dynamic recrystallization (DRX) and metadynamic recrystallization (MDRX) studies. Two typical TiAl alloys were taken as examples, Ti-43Al-4Nb-1Mo-0.1B (TNM) and Ti-48Al-2Cr-2Nb (Ti-4822). Results show that both of DRX and MDRX play an important role in the forging process of TNM alloy, while DRX is the single controlling factor for the forging process of Ti-4822 alloy. By using the hot forging techniques designed by present work, a microstructure with uniform and fine grain size of 8~30μm was obtained. Besides, the constitutive model and recrystallization grain size model were established to predict the hot deformation behaviour and grain size after forging. The proposed hot forging method in the present work yields important information for the development of hot deformation techniques and microstructure controlling strategies of TiAl alloys.

9:25-9:50 Invited (1234965)

Understanding Local Deformation Behaviour of Titanium and Its Alloys Using Experimental Micromechanics

Tea-Sung (Terry) Jun, Incheon National University, South Korea

The deformation mechanisms of titanium and its alloys are still unclear due to their highly localised deformation and elastic/plastic anisotropy inherent to hcp crystal structure. Further complexities arise from microstructural heterogeneity, macro- and micro-texture and/or phase interactions. Small-scale experiments on a localised, confined area are therefore required to improve the understanding of fundamental mechanism on the level of the individual constituents. In recent years, much attention has been paid to developing in-situ micromechanical testing techniques to examine mechanical deformation process at small-scale. Micropillar compression particularly shows an effective way to characterise real time deformation and failure modes of a wide range of materials including complex multi-phase alloys. Further development shows that this technique can be combined with EBSD, allowing quantitative analysis of local elastic strain (hence stress) and the distributions of GND contents during compression. In the present study, combined nanoindentation, micropillar compression and/or (HR)EBSD techniques are used to investigate the evolution of heterogeneous deformation in Ti and its alloys. The in-situ compression tests are performed using a displacement-controlled Alemnis nanoindentation platform set inside a SEM and EBSD patterns were captured using a TSL-EDAX EBSD system. Analysis of each map was performed offline using CrossCourt from BLG productions (Bristol, UK). These experimental approaches present new exciting mechanistic insight into important deformation mechanisms, as well as opening up further studies of new alloy design.

9:50-10:10 (1221705)

Effect of the Initial Microstructure on Aging Behavior in Si-Bearing Near Alpha Titanium Alloy

Tatsuaki Sakamoto, Ehime University, Japan; Hiroaki Akiyama, Shinwa Kogyo Co., Ltd., Japan; Seiya Tange, Primetals Technologies Japan, Ltd., Japan

Aging behavior of a Si-bearing near alpha titanium alloy Ti-1100 has been investigated using specimens having two different initial microstructures: alpha phase and alpha-prime martensite (hereafter denoted as alpha specimen and alpha-prime specimen, respectively). The alpha specimen and the alpha-prime specimen were made by the following heat treatment. Firstly, solid solution treatment was conducted at 1060˚C for 25min, followed by air cooling for the alpha specimen and by iced brine quenching for the alpha-prime specimen. The alpha and alpha-prime specimens consist of almost all alpha phase and alpha-prime martensite, respectively. Silicides are hardly observed in both specimens after the solid solution treatment. Aging was carried out at 600˚C from 5min to 42 day for both specimens. In the case of the alpha specimen, Vickers microhardness decreases during aging from 5 to 625min, and then increases until 42 day. TEM observation revealed that the first decrease in hardness is due to the decrease in dislocation density and the second increase is due to precipitation of silicide and Ti_3Al. On the other hand, in the case of alpha-prime specimen, Vickers microhardness decreases during aging from 5 to 25min, increases from 25min to 625min, decreases from 625min to 4 day, and then increases until 42 day. TEM observation revealed that the first decrease in hardness is due to the decrease in dislocation density, the second increase is due to the precipitation of silicides, the third decrease due to coalescence of the silicides and the last increase due to precipitation of Ti_3Al. The alpha prime specimen initially has considerable dislocations within itself, resulting in promotion of precipitation of silicide showing the peak of hardness during the aging. It is likely that the initial microstructure affects high temperature deformation behavior because precipitation of silicides is related to high temperature deformation in this alloy.

10:10-10:30 (1453925)

Tensile Properties at 700℃ of Ti-Al-Sn-Zr-Mo-Nb-W-Si High-Temperature Titanium Alloys with Different Mo Addition

Xiaoyun Song, Yuwei Diao, Wenjing Zhang, Wenjun Ye, Songxiao Hui, GRIMAT Engineering Institute Co., China

High-temperature titanium alloys have been widely used in the aerospace industry, due to their exceptional properties of strength-to-weight ratio, corrosion resistance, workability and weldability. With increasing the flight speed of short-term high-speed aircraft, the short-time service temperature has reached 700˚C, and traditional long-term high temperature titanium alloys have been unable to meet the requirements. In our previous work, novel Ti-Al-Sn-Zr-Mo-Nb-W-Si short-term high-temperature titanium alloys were designed and the tensile behaviors of the alloys at temperatures to 650˚C have been studied. However, the properties of alloys higher than 650˚C or even 700˚C have not been systematically investigated. In this paper, three Ti-6.5Al-2Sn-4Zr-xMo-2Nb-1W-0.2Si (x=1, 2, 4) alloys (hereinafter termed as 1M2N1W, 2M2N1W and 4M2N1W, respectively) were prepared by vacuum consumable electrode method. The ingots were hot-rolled into 12-mm-diameter bars in two-phase region. The effects of Mo content on the microstructure and tensile properties at 700˚C were investigated through optical microscopy (OM), scanning electron microscopy (SEM) and tensile tests. The results show that after single annealing, the alloys are composed of bimodal structure with equiaxed primary α-phase (α_p) and lamellar transformed β structure (β_t). Fine secondary-α (α_s) that precipitated in the β_t structure. As the content of Mo increases, the average size of the α_p phase is gradually reduced, with the size of β_t is gradually increased, and the thickness of the lamellar α_s phase is also getting finer and finer. Tensile tests at 700˚C show that with the increase of Mo content, the yield strength (YS) decreases while the elongation increases. But the alloy with 2at% Mo addition shows higher ultimate tensile strength (UTS) than the other two alloys. It is considered that the interface strength is weakened dramatically at high temperature especially 700˚C. As the Mo content increases, the α_p phase and α_s phase in the alloy become smaller with the β_t phase increases. The grain is remarkably refined, so the YS shows a decreasing trend, and the plasticity of the alloy has been improved. Moreover, compared to 650˚C, the strengthening effect of Mo element is weakened at 700˚C.

10:30-10:45 Tea Break

10:45-11:10 Invited (1233872)

Heterogeneous Microstructure in Beta Type Ti-Mo Alloy Through Thermomechanical Treatment

Satoshi Emura, Xin Ji, Koichi Tsuchiya, National Institute for Materials Science, Japan

Beta type Ti-Mo alloy exhibits excellent properties such as good balance of mechanical properties and high corrosion resistance. Mechanical properties of titanium alloys are known to be strongly affected by their microstructure. In this talk, I would like to introduce some of our efforts to apply heterogeneous microstructure in Ti-Mo alloys. (i) Mo is an important element for stabilizing beta phase in titanium alloys, but is prone to segregate, i.e. unevenly distributed in Ti-Mo alloys. We use this segregated structure for enhancing mechanical properties of Ti-Mo alloys. Swirly or layered structure caused by elemental segregation was successfully applied through simple thermomechanical treatment, namely hot forging and hot rolling. Using this segregated structure, we can locally control the precipitation behavior of omega phase (hard second phase) and successfully enhance the strength-ductility balance of Ti-Mo alloy. (ii) Recently, long period stacking structure (LPSO) was found in magnesium alloys and this type of layered structure (so called Mille-feuille structure) seems to have some effects on mechanical properties of other materials than magnesium. We have obtained Mille-feuille like layered precipitation of alpha phase in beta matrix by the combination of slight cold rolling and following aging treatment.

11:10-11:35 Invited (1313976)

Deformation Compatibility in Dual Phase Ti Alloys Under Compression

Renlong Xin, Ke Wang, Qing Liu, Chongqing University, China

Dual phase titanium (Ti) alloys are widely used as airplane structural parts due to their high specific strength and very attractive combinations of strength, toughness and fatigue resistance. Such superior mechanical properties are intimately related to the deformation compatibility between the alpha and beta phases. Fracture usually initiates at phase interface during fabrication and service of Ti alloys. Therefore, it is important to investigate the behaviors of deformation and crack initiation in dual Ti alloys and hence figure out the correlations with microstructural and crystallographic features. Based on the observations on slip trace and crystallographic orientation, the activated slip systems in TC21 and TA19 Ti alloys are determined after compression deformation, and their corresponding Schmid factor (SF) and geometric compatability parameter (m') were calculated and analyzed. The m' for most active slip systems of alpha and beta phases in TC21 has a high value, indicating a good strain compabitility at phase interface. Difficult slip transfer occurs at a low m' or low SF in TA19, which induces stress concentration at grain boundaries, and then causes a corresponding crack nucleation. Moreover, the displacement gradient induced by dislocation glides in one phase is transferred to another phase by tensor analysis, which is then used to explain the observed strain compatibility phenomena at phase interface. These deformation and fracture behaviors in dual phase Ti were discussed and considered as crystallographic orientation dependent.

11:35-11:55 (1233672)

The Influence of Chemical Composition on the Grain Boundary Network Characteristics in Ti Alloys

Hossein Beladi, Ehsan Farabi, Peter Hodgson, Deakin University, Australia

The effect of chemical composition on the intervariant boundary network characteristics during martensitic phase transformation was studied using the crystallographic theories of displacive transformation and the 5 parameter boundary analysis. The martensitic microstructure of two titanium grades, namely commercially pure Ti (CP-Ti) and Ti-6Al-4V alloy; was examined using TEM and EBSD techniques. The CP-Ti had a coarse martensitic microstructure consisting of dislocated laths while the Ti-6Al-4V alloy showed fine twinned laths. There was a distinct difference in misorientation angle distribution of two martensitic microstructures, although the peaks were consistent with the Burgers orientation relationship. The martensitic CP-Ti had a distinct peak at the 60° misorientation angle corresponding to the 60° / [1 1 -2 0] intervariant boundary while the Ti-6Al-4V had a peak around the 63.26° misorientation angle related to the 63.26° / [-10 5 5 -3] intervariant boundary. This discrepancy was rationalized using phenomenology theory of martensite transformation. It was predicted that the difference in the chemical composition leads to different strain levels during the martensitic transformation. This resulted in the occurrence of a local variant selection mechanism to self-accommodate the transformation strain. In this regard, different variant clustering in martensitic CP-Ti (i.e., 3-variant, triangular morphology) and Ti-6Al-4V (i.e., 4-variant, quadrilateral morphology) was predicted and observed. It was concluded that the local variant selection during martensitic transformation influenced by the chemical composition stimulated specific intervariant boundaries in the Ti-alloy microstructure. Finally, the change in the self-accommodation morphology resulted into the promotion of pyramidal (1 0 -1 1) interfaces in the CP-Ti martensite, while the prismatic interfaces was favoured in the Ti-6Al-4V martensite.

C3. Light Metals and Alloys: Ti and Others II

Symposium Organizers :

Yongqing Zhao, Northwest Institute for Nonferrous Metal Research, China; Yoshihito Kawamura, Kumamoto University, Japan; Young Min Kim, Korea Institute of Materials Science (KIMS), Korea; Jian-Feng Nie, Monash University, Australia; Diran Apelian, Worceste Polytechnic Institute, USA

Tuesday PM　　Room: VIP 304 (3rd Floor)
August 20, 2019　　Symposium: C3

Chairs:
Elena Pereloma, University of Wollongong, Australia
Yongqing Zhao, Northwest Institute for Nonferrous Metal Research, China

13:30-14:00 Keynote

R & D of New Titanium Alloys in China

Yongqing Zhao, Northwest Institute for Nonferrous Metal Research, China

Because of their excellent comprehensive properties, Ti and its alloys have been wide used in many industry fields. This paper review the R & D of new titanium alloys developed in China in recent 10 years, such as TC21 alloy with high strength and high toughness, TC4-DT alloy with middle strength and high toughness, Ti-1300, Ti26 and Ti-B19 alloys with super high strength, Ti75 and Ti31 alloys used for shipbuilding and so on. And also this paper will show the applications of these new alloys.

14:00-14:25 Invited (1300408)

Novel Approaches to Surface Engineering of Ti Alloys

Mingxing Zhang, Shoumou Miao, Queensland University, Australia

The lightness, high strength and excellent corrosion resistance are the major advantages of Ti alloys, which attract increasing interest in wider industrial applications. However, this type of alloy also suffers from poor oxidization resistance due to the high chemical reactivity and low wear resistance. Thus, the currently available Ti alloys, such as Ti1100, Ti6242S, can only be used at temperatures below 600˚C. In order to apply the Ti alloys to higher temperatures, the oxidization problem must be overcome. We report one novel approach to surface treatment of Ti alloys in this presentation. The treatment can lead to formation of a coating with controllable thickness ranging from 100μm to 2000μm on any Ti alloys. The coating not only effectively prevents the Ti substrate from oxidization in air up to 1000˚C for 72 hours, but also significantly improves the wear resistance. Therefore, there is strong potential to replace some Ni-based or Co-based superalloys with Ti alloys for high temperature applications, and therefore to reduce the cost. In addition, the technique is characterized with low cost, reliable and high bond strength with the substrate. Thus, the reported results have both technological and economic significances. Microstructures of the coating will also be discussed in the present work.

14:25-14:50 Invited (1223091)

Creep Deformation of Near-Alpha Ti Alloys

Yoko Yamabe-Mitarai, Tetsuya Matsunaga,Yoshiaki Toda, National Institute for Materials Science, Japan; Kei SHIMAGAMI, Haruki Masuyama, Shibaura Institute of Technology, Japan; Tsutomu Ito, Toyama Prefectural University, Japan

Near alpha Ti alloys are used as compressor blades or disks in jet engine. However, Ti alloys can not be used above 600˚C because oxidation and creep resistances become low above 600˚C. Operation temperature of jet engine is raising to reduce green gas and fuel consumption. Then, Ni-based superalloys with density twice as high as that of Ti alloys are used even in the high-temperature latter parts in compressors. However, using Ni-based superalloys increase the weight of jet engine. Then, it is very important to develop new high-temperature Ti alloys. Generally, microstructure related with mechanical properties is drastically changed by plastic deformation such as forging and rolling. Then, in this paper, the way to control microstructure of Ti alloys by changing forging and rolling condition was investigated. Then, using samples with different microstructure formed by different plastic deformation, the effect of microstructure factor on creep deformation was systematically investigated to understand creep deformation and decide the direction of alloy design. At first, the role of alloying elements was investigated to improve oxidation resistance. It is found that Sn degrades oxidation resistance and Nb improves oxidation resistance. Although Sn is a mandatory element for a-Ti alloys to stabilize a phase and strengthen a phase by solid solution hardening, we have attempted to design new Ti alloys without Sn. Nb is chosen as alloying element to improve oxidation resistance. To expect solid-solution hardening, Zr is also added to the alloys. The alloy ingots were melted using the cold-crucible levitation melting method, forged and groove-rolled to produce a bar with 14mm in diameter at 900 and 1000˚C with different deformation ratio. Samples were cut from a bar and heat treated in different conditions. The model microstructures such as equiaxed single alpha phase, equiaxed alpha phase with Ti_3Al precipitates, equiaxed alpha phase with silicide precipitates, alpha + alpha' -martensite phase and equiaxed alpha phase surrounded by beta phase were prepared by changing heat treatment. The creep behavior of the model microstructure was investigated at temperature range between 550 and 650˚C under stress range between 69 and 242MPa. The effect of each microstructure factor, such as Ti_3Al precipitates, silicide, alpha' and beta phases on creep deformation was clarified.

14:50-15:10 (1221774)

The Mechanism of {332}<113> Twinning Combining Metastable Phases in Metastable β-Type Ti-Mo Alloys Based on Cluster Structure

Mingjia Li, Xiaohua Min, Dalian University of Technology, China

Metastable β-type Ti alloys have attracted considerable attention as promising materials for biomedical and marine engineering applications due to their excellent properties such as low Young's modulus, good biocompatibility, high resistance to corrosion, shape memory effect and superelasticity. Twinning is an important deformation mechanism and plays a very important role in twinning-induced plasticity (TWIP) effect as it results in an extra strain hardening. An unusual twinning mode, {332}<113> twinning, is one unique deformation mechanism metastable β-type Ti alloys and is described by several models such as, shear and shuffle mode, α″ martensite transformation mode, dislocation mode and lattice instability mode. However, the modes as described above did not considered the influence of metastable phases, and the origin of {332}<113> twinning remains unclear. In this paper, the mechanism of {332}<113> twinning was investigated by considering the existence of the metastable phases (ω-phase and O'-phase) in body-centered-cubic (bcc) β-matrix. The magnitudes of twinning shear and shuffle were evaluated in different modes to find out the most possible mode to describe the formation of {332}<113> twinning. Besides, comparing the magnitudes of shear and shuffle between {112}<111> and {332}<113> twinning to clarify the competing relationship between them. The results showed that the shear magnitude of {332} plane along <113> direction was 5√11/22aβ (0.7538aβ) when {332}<113> twinning proceeded via the single shear mode. However, in the shear and shuffle mode, the magnitude of atomic displace were √11/44aβ (0.0754aβ) and √22/11aβ (0.4264aβ), respectively, which were less than the former mode. Moreover, under the softening effect of shear modulus along <111> direction (G111), the {112} plane moved along <111> to form ω-phase, which made the shuffle magnitude reduced to 0.2843aβ at most concerning the influence of Mo content and cluster structure. The low tetragonal shear elastic constant (C') of β-phase made the {110} plane shuffled along <110> direction to form O'-phase. In this process, the atoms were shuffled to their correct twin positions. Therefore, the formations of metastable phases were conductive to {332}<113> twinning. In addition, the magnitudes of shear and shuffle in {332}<113> twinning were smaller than those in {112}<111> twinning via the formations of metastable phases. Therefore, the new mechanism of the {332}<113> twinning presented in this study can explain how the metastable phases preferentially activates the {332}<113> twinning in metastable β-Ti alloys instead of the {112}<111> twinning which is a major twinning mode observed in alloys with stable bcc structure.

15:10-15:30 (1222600)

Investigation of Strain Rate Strengthening and Work Hardening Behaviors in a Twinning-Induced Plasticity Ti-15Mo Alloy

Kai Yao, Xiaohua Min, Dalian University of Technology, China; Satoshi Emura, Koichi Tsuchiya, National Institute for Materials Science, Japan

The metastable β titanium alloys with twinning-induced plasticity (TWIP) effect show a wide application prospect in the aerospace, biomedicine, and energy industries due to their excellent mechanical properties with high strength, high ductility, and excellent work-hardening behavior. Some studies demonstrated that the mechanical properties of metastable β titanium alloys with TWIP effect remarkably depended on the strain rate, which exhibited the negative strain rate sensitivity (SRS). The SRS should be divided into instantaneously strain rate sensitivity (ISRS) and strain rate sensitivity of work-hardening (SRSW). The former part represented the effect of strain rate on flow stress, and the latter part represented the strain rate effect on microstructural evolution, i.e. the change of work-hardening rate. In the present study, the continuous tensile experiments at various strain rates and strain rate jump experiments were designed to investigate ISRS and SRSW in a twinning-type Ti-15Mo alloy, and a slip-type Ti-6Al-4V as a comparison material. The Ti-15Mo and Ti-6Al-4V alloys were prepared by cold crucible levitation and vacuum consumable arc melting. After solidification, the ingots were subjected to homogeneous treatment, hot forging, hot rolling and solution treatment. The tensile specimens with a gauge length of 25mm(l)×4mm (w)×1mm(t) were cut from the solution treated plates. The monotonic tensile tests up to fracture were performed on an UTM4204X testing machine at different strain rates ranging from 1.11×10^{-5} to $1.11\times10^{-1}s^{-1}$. The tensile specimens were stretched to various true strains (0.00, 0.05, 0.10, 0.15, 0.20 and 0.25) at constant strain rates of $1.11\times10^{-4}s^{-1}$ and $1.11\times10^{-1}s^{-1}$. The tensile specimens were first loaded with a stain rate

of 1.11× $10^{-4}s^{-1}$ to the true strains of 0.00, 0.05, 0.10, 0.15 and 0.20, and then instantaneously jumped to higher strain rate up to fracture. In the Ti-15Mo alloy, the yield stress monotonously increased, while the ultimate tensile strength and elongation gradually decreased as increasing strain rate. The Ti-15Mo alloy exhibited negative SRS, and the coefficient of SRS was positive at a smaller strain level (<0.08), further decreased to the negative value as increasing strain. It demonstrated a positive ISRS in this alloy, which gradually increased as increasing jumping strain. The negative SRS was attributed to the much negative SRSW, i.e. lower work-hardening rate at higher strain rate. In the $Ti^{6}Al^{4}V$ alloy, as increasing strain rate, the yield stress and ultimate tensile stress gradually increased, while the elongation decreased. The SRS and SRSW of this alloy were also negative, and a positive ISRS was found, which was stable regardless of jumping strain.

15:30-16:10 Tea Break

16:10-16:35 Invited (1222001)

Modelling of Materials Flow at Elevated Temperatures

Zhanli Guo, Sente Software Ltd., UK

Materials flow is governed fundamentally by deformation mechanisms, which should remain unchanged regardless of the means of experimental investigations. However, for historical reasons, deformation mechanisms have been presented in various laws depending on the means of testing. For example, the deformation mechanism maps proposed by M. F. Ashby are based on creep mechanisms, whereas many of the laws describing strain or work hardening are derived from tensile or compression testing. There are many constitutive equations available describing the stress-strain behaviour at elevated temperatures. Strictly speaking, these equations are not based on deformation mechanisms, but rather empirical in nature. All these laws can be unified, at least in principle, if the common assumption that stress-strain relation is path-independent prevails. This paper looks at materials flow of various alloy systems such as Ti-, Al- and Mg-alloys. The constitutive equations, such as the Johnson-Cook type or the Norton-Hoff type which are used to describe flow stress curves at elevated temperatures, can now be replaced by appropriate creep laws.

16:35-16:55 (1259332)

In-Situ EBSD Investigation of As-Built Laser Direct Melting Deposited (LDMD) Ti-6Al-4V Component at Moderate Temperature 200℃

Rafi Ullah, Beijing University of Technology, China

Laser direct metal deposition (LDMD) is quite new developed additive manufacture (AM) process. LDMD based Ti-6Al-4V component promisingly offers cost-effective alternate route to meet the severe demands of the modern aircraft industry. The OM and SEM results show that the structure of the as-built sample is more complex with beta columnar grains solidified in the building direction with interior covered of fine randomly oriented alpha laths which can lead to different unbalance deformation behavior during tensile test that needs to be better understood. Analysis of EBSD reveals that the as-built sample structure contains 89% volume fraction of alpha phase with small amount 11% of beta phase, rogue alpha grain combinations and different crystal orientations. Microstructural features relation with deformation behavior, and interesting effect of grain orientation, recrystallized fraction, schmid factor at moderate temperature 200˚C were investigated by direct In-situ EBSD observation technique during tensile testing. With the increase of tensile stress, maximum intensity of the texture of alpha phase first slightly increases from 33.01 to 35.63 and then dropped to 28.59. It has been observed that alpha plates having axes roughly parallel to the tensile axis easily deformed and present high discontinuity. Moreover, crystal in which the c-axis of the unit cell roughly inclined to the tensile axis exhibited easily slip lines after tensile.

16:55-17:15 (1222401)

True Stress - True Strain Curve up to Large Strain Obtained by Image Analysis Tensile Test Method at Elevated Temperature in Ti-17 Alloy

Atsushi Ito, Kiminori Taga, Shiro Torizuka, University of Hyogo, Japan

For aerospace applications, Ti-17 alloy has been applied for engine parts due to its excellent strength and toughness. They are mainly formed parts by hot forging. To evaluate hot forgeability, uniaxial compression test is common test method. However, in uniaxial compression tests, strain distribution is not introduced uniformly inside of the specimen due to the friction between a specimen and an anvil, resulting in large strain concentration in the center of the specimen. On the other hand, in tensile test strain is introduced uniformly inside a specimen up to the start of necking. However, the strain of necking start is generally small, it’s difficult to obtain stress-strain curve up to large strain. To solve this problem, we have developed the image analysis tensile test method enabled us to evaluate accurate stress-strain curves after necking up to fracture at room temperature. The image analysis devices equipped with thermomechanical treatment simulator enables us to measure the change in the necking geometry during a tensile test at elevated temperature. From the necking geometry data, true stress after necking can be calculated by Bridgeman equation. In the present work, the image analysis tensile test method at elevated temperature is carried out and the accuracy of obtained true stress- true strain curves are evaluated in Ti-17 alloy. True stress decreased slightly after yielding at 1000˚C and at the strain rate of $0.01s^{-1}$ tensile test. In conventional compression test, at the strain rate of 0.1 and $1s^{-1}$, true stress decreased largely. On the other hand, true stress in tensile test increased after yielding. The microstructure in the specimen compressed at the strain rate of $1s^{-1}$ was deformed microstructure including little recrystallized grains. Therefore, in compression test, geometrical change and non-uniform strain distribution in a specimen rather than metallurgical structural change inside largely affect true stress – strain curve, resulting in the inaccuracy in the curve. This image analysis tensile test method can obtain accurate true stress – strain curve which is directly attributed to metallurgical structural change.

17:15-17:35 (1222430)

Direct Imaging of Short-Range Displacive Order in a Pre-Martensitic State of Ti-Ni-Fe Shape Memory Alloys

Ryouhei Kinoshita, Daisuke Egusa, University of Tokyo, Japan; Yasukazu Murakami, Graduate School of Engineering, Kyusyu University, Japna; Eiji Abe, National Institute for Materials Science, Japan

Pre-martensitic phenomena are critical issues for understanding B2-phase to R-phase martensitic transformations of Ti-Ni-Fe alloys, which are well known as shape memory materials. The phenomena are characterized by such as diffuse scattering in electron diffraction which suggest structural modulations formed by small atomic displacements correlated to the martensite shear. Based on the electron diffractions, the modulations are interpreted as a transvers-type displacement wave, whose propagation and displacement vectors are <110> and <1-10>, respectively. However, details of this precursor phenomena are still unclear, because magnitude of expected displacements is quite small, which is considered on order of picometers. To clarify the phenomena, we investigated atomistic details of pre-martensitic states in Ti50Ni48Fe2 alloys with HAADF-STEM observations. [1-11] projected STEM image shows fluctuation of column intensities that form intensity modulation along <110> directions, although there is no difference in [1-11] projected potentials between atomic columns. We found out that such intensity fluctuations derived from small atomic displacements with transvers-type modulation that affect the scattering behavior of electrons contributing for HAADF imaging, based on multi-slice STEM simulations. The modulations of image intensity are also confirmed by diffuse scattering appear in a power spectrum of filtered HAADF-STEM image, which correspond with the one shown in conventional electron diffraction. We constructed a structural model of the transverse-type atomic displacements based on the image analysis and STEM simulations. In addition, based on diffuse scattering within the power spectrum, it is suggested that sizes of each modulation modes were estimated as about 1~2nm in diameter, and they form domains with each of 6 variants of modulation waves. Distributions of those domains uniformly spread in the specimen, implying that the pre-martensitic phenomena are second-order-like transition process. Entropy difference accompanying with the transition was estimated by configurational entropy of domains based on the model, showing close value to the one accompanied with B2 to R transformation.

17:35-17:55 (1221749)

Synergistic Effect of Pre-Deformation Microstructures and Isothermal ω-Phase on Mechanical Properties of Ti-10Mo Alloy

Shichao Ma, Xiaohua Min, Dalian University of Technology, China; Satoshi Emura, Koichi Tsuchiya, National Institute for Materials Science, Japan

β titanium alloys have been widely used in aerospace, biomedical and other industrial fields owing to its high specific strength, corrosion resistance, excellent aging strengthening (ω and α phase) and many other excellent properties. A simultaneous improvement in both strength and ductility by means of a single deformation mode or second-phase precipitated appears to be difficult for β titanium alloys to achieve large uniform elongation while keeping high yield strength. An improved strength-ductility in twinning-type Ti-15Mo alloy was found by means of pre-deformation induced {332}<113> twinning and subsequently isothermal ω phase precipitation. However, relatively little attention has been given to the complex deformation modes consisting of α" martensite, {332}<113> twining and dislocation in β titanium alloys. The purpose of this study is to confine the suitable degree of pre-deformation and appropriate aging temperature on the tensile properties in Ti-10Mo alloy. An approximately 1kg ingot of Ti-10Mo alloy was prepared by cold crucible levitation. After solidification, the ingot was homogenized at 1273K for 3.6ks and then hot-forged at 1273K, hot-rolling at 1173K, subsequent aging at 473~673k for 3.6ks. Four types of samples were used in this study: ST (solution-treated) and STA (solution-treated and aged) samples, which were tensile specimens (gauge dimensions: $20(l)mm \times 4(w)mm \times 1(t)$ mm), STD (solution-treated and deformed) and STDA (solution-treated, deformed, and aged) samples, which were pre-deformation specimens made by deforming ST specimens to 2%, 5%, 10%, 20% and 30% tensile strain prior to aging. Tensile tests were performed at room temperature in a tensile test machine Instron-5581 at an initial strain rate of $2.78 \times 10^{-4}s^{-1}$. Vickers hardness was measured with a load of 1kgf at ten positions on the transverse plane of each sample, with their average taken as the value for that sample. The microstructure was observed by optical microscopy (OM). Phase identification was made by X-ray diffraction (XRD) with an EMPYREN diffractometer using CuKα radiation. More stress induced α" martensite and {332}<113> mechanical twins were refined with the increasing degree of pre-deformation. The Vickers hardness gradually increased with an increase of precipitating temperature, which was resulted from the precipitation of brittle ω phases. The favourable strength-ductility tradeoff in Ti-10Mo alloy was achieved through the 20% pre-deformation and aging at 523K for 3.6ks. The high yield strength was mainly dominated by the precipitation strengthening of isothermal ω phase, and the enhanced uniform elongation was attributable to pre-existing twins and α" martensite as well as the subsequently dynamic microstructural refinement due to the {332}<113> twin and α" martensite during tensile deformation.

C3. Light Metals and Alloys: Ti and Others III

Symposium Organizers :

Yongqing Zhao, Northwest Institute for Nonferrous Metal Research, China; Yoshihito Kawamura, Kumamoto University, Japan; Young Min Kim, Korea Institute of Materials Science (KIMS), Korea; Jian-Feng Nie, Monash University, Australia; Diran Apelian, Worceste Polytechnic Institute, USA

Thursday AM
August 22, 2019

Room: VIP 304 (3rd Floor)
Symposium: C3

Chairs：
Qiaoyan Sun, Xi'an Jiaotong University, China
Lei Li, Northwest Institute for Nonferrous Metal Research, China

8:30-8:55 Invited (1235037)

Effect of Calcium Treatment on the Control of Inclusions in Al Deoxidized Special Steel

Qiaoyan Sun, Pei Li, Lin Xiao, Jun Sun, Xi'an Jiaotong University, China

Strength and ductility of Ti-55531 (Ti-5Al-5Mo-5V-3Cr-1Zr) alloy with two different microstructures was investigated. The super-refined a precipitates together with grain boundary alpha file from beta solid solution and double aging (M1) and bimodal microstructure (M2) from alpha+beta solid solution and double aging were characterized using transmission electron microscopy, scanning electron microscopy and image analysis software. The results indicate that the samples with M1microstructure show brittle fracture in tensile tests. While the samples with M2 microstructures exhibits ductile fracture in tensile tests. The heterogeneous plastic deformation takes place within different morphology of α during deformation. The grain boundary alphas are softer than the precipitation hardened beta matrix. As a consequence, strain localizes in the beta grain boundary alpha severely and brings about crack and supply a low energy path for crack propagation, which leads to intergranular fracture. The microstructure (M2), including primary α phase together with alpha precipitates in beta matrix and grain boundary alpha, improves the ductility of samples in tensile tests. Slip is the dominant deformation mode in the equiaxed primary alpha in tensile deformation and occurrence of the multiple slip systems release the stress concentration at the equiaxed primary alpha /betatrans interface which delay crack formation. The cracks are difficult to grow in the beta matrix hardened by finer alpha precipitates due to high strength or connect each other because of scattered primary alpha. Therefore, Ti-55531 alloy with equiaxed primary alpha shows trans granular fracture and improvement in ductility is observed.

8:55-9:15 (1222649)

Increasing Mechanical Compatibility of Ti-13Nb-13Zr Utilizing Cold Caliber-Rolling

Taekyung Lee, Pusan National University, South Korea; Chan Hee Park, Korea Institute of Materials Science, South Korea

Good mechanical properties and biocompatiility of Titanium alloys leads to their wide applications in the biomedical industry as bone plate, bone screw, hip joint, and dental implant fixture. Ti-13Nb-13Zr alloy, developed at the early 90s, is an ASTM-registed material for implant applications (ASTM F1713). The developed thermomechanical processing route of this alloy gives rise to an elastic modulus of either 65GPa (after solution treatment) or 80GPa (after solution treatment and subsequent aging). Although these numbers are lower than conventional implant alloys, such as Co-Cr-Mo (227GPa) and Ti-6Al-4V (115GPa), they are still higher than an elastic modulus of human bone (20~40GPa) as well as those of recently developed β-phase Ti alloys including Ti-Nb-Ta-Zr alloy. We propose a novel thermomechanical process to significantly decrease an elastic modulus of Ti-13Nb-13Zr, which is denoted as a cold caliber-rolling (CCR). The solution-treated alloy was subjected to CCR up to 12 passes of deformation to obtain fine-grained microstructure and bulk dimension (>1m). Interstingly, the entire CCR samples showed lower elastic moduli than those fabricated via the ASTM procedure. Furthermore, the value kept decreasing with an increasing number of CCR passes. Such a tendency has been doubly confirmed using an uniaxial tensile test (to caculate the slope of elastic range) and ultrasonic measurement. It should also be noted that the suggested method also enhanced mechanical strength of Ti-13Nb-13Zr alloy to ~1GPa. As a result, the parameter of mechanical compatibility, defined as the ratio of yield strength to elastic modulus, significantly increased after applying the CCR process. This result had not been found in our previous study which utilized a warm caliber-rolling instead of CCR, suggesting that the temperature would play a key role in the enhanced mechanical compatibility. The mechanisms were investigated in light of grain refinement, dynamic recrystallization, texture development, and phase transformation.

9:15-9:35 (1382376)

Microstructure and Properties of Low-Ti Nitinol Powder manufactured by Supreme-Speed PREP

Xiaohao Zhao, Shujin Liang, Yunjin Lai, Qingxiang Wang, Chen Wang, Sino-Euro Materials Technologies of Xi'an Co., Ltd., China

Nitinol, mainly consisting of titanium and nickel, is categorized as a shape memory alloy that attracts interests in the vast industries of engineering such as aerospace, bio-medical and other basic industries. The characteristics of Nitinol like shape memory property, bio-compatibility, and pseudo-elasticity make it ideal for making medical implants and aerospace additive manufacturing (AM) components. SS-PREP spherical powder is an effective assistance for intricate AM geometric structure, which are impossible to prepare by conventional machining. In this paper, the characteristics (including fluidity and apparent & tap density) and microstructures of three different particle sizes' powders were investigated, including 15~53μm, 53~106μm, and 106~150μm. Owing to various effect of particle size, shape and surface roughness, 53~106μm powder has best Hall fluidity with 13.97s/50g, apparent densitywith 3.92g/cm^3 ,and tap density with 4.34g/cm^3. Scanning electron microscopy (SEM) photos indicates the coarser particles are, the better sphericity them have. On the contrary, the finer particles were tend to reach egg-like shape. The molten droplet is prone to form dendritic microstructure when its cooling rate is $<2.74\times105K\cdot s^{-1}$ (particle size above 53μm), while some droplets tend to form smooth martensitic structure when its cooling rate is above $2.74\times105K\cdot s^{-1}$ (particle size under 53μm). With the increase of particle size distribution from 15~53μm to 106~150μm, the tested microhardness reduces from 322.9HV to 286.5HV.

9:35-9:55 (1232551)

TRIP and TWIP as Well as the Influence of ω Phase on These Two Phenomena in a Metastable β Ti Alloy

Minjie Lai, Northwestern Polytechnical University, China; Dierk Raabe, Max-Planck-Institut für Eisenforschung GmbH, Germany; Tong Li, Institute for Materials & ZGH, Ruhr-Universität Bochum, Germany

Metastable β titanium alloys are of particular interest for structural applications in aerospace and biomedical industries. Here, we have investigated the twinning-induced plasticity (TWIP) and transformation-induced plasticity (TRIP) as well as the influence of ω phase on these two phenomena in a metastable β-type Ti–25Nb–0.7Ta–2Zr (at.%) alloy. We set off with two starting states: one is ω-free and the other one contains a high number density ($(3.20\pm0.78)\times1024m^{-3}$) of nanometer-sized (~1.23nm) ω particles. Deformation experiments demonstrate that the plastic deformation of the ω-free alloy is mediated by stress-induced β →α" martensitic transformation, {332} twinning and dislocation slip, where the former two induce joint TRIP and TWIP effects and the latter one carries the majority of the plastic strain. In the ω-enriched alloy, the ω particles fully suppress the TWIP and TRIP effects and promote localization of dislocation plasticity into specific ω-devoid channels. Atom probe tomography analysis reveals that the elemental partitioning between β and ω results in only subtle enrichment of solutes in the β matrix, which cannot sufficiently stabilize the matrix to prevent martensitic transformation and twinning. A new mechanism based on the shear modulus difference between β and ω is proposed to explain the suppression of TRIP and TWIP effects by ω particles.

9:55-10:15 (1235512)

Trace of Yttrium Addition on Refining Prior-Beta Grains of Ti-6Al-4V Alloy

Duyao Zhang, Dong Qiu, Mark Easton, Royal Melbourne Institute of Technology, Australia; David StJohn, University of Queensland, Australia; Mark Gibson, CSIRO，Australia

Grain refining titanium and its alloys during solidification can significantly reduce casting defects, enhance mechanical properties and improve formability in the subsequent thermomechanical process. The potent grain refiner also plays a key role to convert columnar grains to equiaxed grains in additively manufactured Ti components. However, potent grain refiner for Ti alloys is limited in types. In this paper, we will present our recent work on refining prior-β grain of as-cast Ti-6Al-4V alloy though trace additions of yttrium. Pre-mixed elemental yttrium and Ti-6Al-4V powders was cold compacted and then arc melted to button ingot. Microstructures analysis revealed that columnar-to-equiaxed transition (CET) of prior-β grains occurs at certain amount of yttrium additions. The grain refining mechanisms of yttrium inoculation include (i) the grain growth restriction effect from in situ formed nano sized yttria particles, (ii) possible heterogeneous nucleation of β-phase around the micro-sized yttria particles and (iii) superior constitutional supercooling delivered by solute yttrium during solidification. In addition, laser surface remelting was applied on the button ingot and much smaller equiaxed prior beta grains were observed in the melt pool compared to the as-cast sample. It suggests that yttrium could be an efficient β-Ti grain refiner for Ti-6Al-4V alloy for additive manufacturing.

10:30-10:45 Tea Break

10:45-11:05 (1484108)

Quantitative Evaluation of Synergetic Strengthening Mechanisms in Carbon Nanotubes Reinforced Titanium Metal Matrix Composites

Khurram Munir, Cuie Wen, Yuncang Li, RMIT University, Australia

Carbon nanotubes (CNTs) are considered as promising reinforcement materials for metal matrix composites (MMCs) because of their unique mechanical properties. However, their dispersion in MMCs is challenging because of their tubular morphology, high surface areas, and nano-scale dimensions. Powder metallurgy has emerged as an excellent technique to effectively disperse these CNTs in MMCs. Despite the effective dispersion of CNTs in the MMCs, harsh milling conditions damage the CNTs and eventually CNTs lose their unique properties. In this work, titanium (Ti) metal matrix composites (TMCs) reinforced with multi-walled carbon nanotubes (MWCNTs) were fabricated by powder metallurgy. MWCNTs (0.5wt.% and 1.0wt.%) were dispersed into Ti powders through two different dispersion processes; (i) high energy ball milling (HEBM), and (ii) solution ball milling (SBM) process. The solid-state interfacial reactions between MWCNTs and Ti were controlled through optimizing the dispersion processing conditions. The Ti-MWCNTs powder mixtures were consolidated and sintered at 1100˚C in a vacuum furnace. The graphitization induced strengthening efficiency and various strengthening modes in the fabricated composites were quantitatively characterized. The relationships between the graphitization and the key synergetic strengthening modes were established. The Ti-0.5wt.% MWCNTs composites with in situ formed titanium carbide (TiC) nanorods during HEBM and debundling of MWCNTs during SBM processes exhibited compressive yield strength of 882 MPa and 920MPa which demonstrated 18% and 32% increase compared to commercially pure titanium (CP-Ti), respectively. The key strengthening modes included grain refinement, dispersion strengthening of homogenously dispersed MWCNTs and in-situ TiC particles, solid solution strengthening of carbon, oxygen and nitrogen in Ti matrix, and load-bearing strengthening in TMCs.

11:05-11:25 (1235071)

Microstructure Effect on Fatigue Stability and Fatigue Damage Mechanism of a Near β Titanium Alloy Ti7333

Zhihong Wu, Hongchao Kou, Wei Chen, Jiangkun Fan, Bin Tang, Jinshan Li, Northwestern Polytechnical University, China; Xiaoning Han, Ying Deng, AVIC Manufacturing Technology Institute, China

Due to its excellent mechanical and physical properties, including high specific strength, excellent corrosion resistance and high temperature strength, the near β titanium alloy has been widely used in aviation and aerospace fields. For aerospace structures to withstand alternating loads, high cycle fatigue failure is one of the main failure modes. Near β titanium alloys exhibit high fatigue performance causing increased interest in studying the microstructure-fatigue stability relationship and the underlying fatigue damage mechanisms. The material selected for this work is a new near β titanium alloy, Ti-7Mo-3Nb-3Cr-3Al. The thermomechanical processing routes were designed to produce different volume fractions of globular primary-α particles distributed in a matrix of transformed-β structure consisting of very fine secondary-α precipitations. Axial loading fatigue tests were conducted on smooth hour-glass specimens (K_t=1). The tests were run in load-controlled at RT and a lab-air environment, using a sinusoidal waveform with an R ratio of 0.1. A frequency of around 120Hz were used. Results show that the solution aged microstructure renders the alloy with a significantly higher fatigue strength of 927MPa. Besides, the fatigue stability increase with increasing of α_p percentage. The fracture morphologies pointed to at least five categories of fatigue crack-initiation modes: (i) β (isolated α_p) facets; (ii) β (several isolated α_p) facets; (iii) isolated α_p facet; (iv) several isolated α_p facets; and (v) isolated β facet. Furthermore, the formation of compound α/β facets is due to the cleavage fracture of α grains, then the crack propagate to the β grain boundary. In addition, α facets form on or very near basal planes, and β facet form on (110) plane with the maximum Schmid factor.

11:25-11:45 (1488539)

Effect of β Solutiuon Treatment on Microstructure and Dynamic Mechanical Properties of Ti-6Cr-5Mo-5V-4Al Alloy

Yang Yu, Wenjing Zhang, Wenjun Ye, Songxiao Hui, GRINMAT Engineering Institute Co, Ltd. Beijing, PR. China

Beta titanium alloys are attractive candidates for aerospace, automobile, orthopedic implant and down-hole service applications due to their unique combination of high specific strength, excellent hardenability, good fatigue performance, and excellent corrosion resistance. Ti–6Cr–5Mo–5V–4Al alloy is a new metastable beta alloy developed by BaoTi Group as thick-section structural materials for aerospace applications. Its design was to achieve an excellent combination of high strength and good ductility based on multicomponent strengthening.

In this work, we have studied the microstructure and dynamic mechanical properties of a Ti-6Cr-5Mo-5V-4Al alloy bar with 300mm in diameter. The samples were solution treated above the β transformation temperature. The result showed that the grain size increased with prolonging solution time when the alloy was solution treated at 890˚C. In addition, the acceleration of the grain growth occurred when solution time is more than 60min. When the alloy is solution treated at 890˚C, the function of grain growth followed by an equation = 165t 0.449. When the alloy was solution treated for 60min, grain size increased with increasing the solution temperature, and grain coarsening occurred at temperatures above 890˚C. Within the ranges of the solution temperature and time in the present study, the grain size was more sensitive to the solution temperature than the solution time. In order to avoid grain growth and coarsening, the suggested solution treatments for the Ti-6Cr-5Mo-5V-

4Al alloy is 800~900˚C for 15~60min. The true stress-strain curve of the β phase exhibited significant strain softening under dynamic loading. The samples with the finest grain size exhibited the best performance under dynamic loading. With increasing the grain size, there is a slight deterioration in their dynamic performance. However, the uniform plastic strain and the maximum absorbed energy did not decrease significantly. Twin related structures were observed inside the β grain of the samples after dynamic compression deformation, indicating that twinning occurred during dynamic loading. The occurance of twinning had no significant influence on the values of the average stress, while improved the values of uniform plastic strain and maximum absorbed energy.

C3. Light Metals and Alloys: Ti and Others

Symposium Organizers :

Yongqing Zhao, Northwest Institute for Nonferrous Metal Research, China; Yoshihito Kawamura, Kumamoto University, Japan; Young Min Kim, Korea Institute of Materials Science (KIMS), Korea; Jian-Feng Nie, Monash University, Australia; Diran Apelian, Worceste Polytechnic Institute, USA

August 19-21, 2019
Room: Exhibition Area (3rd Floor)

C3-1: Effect of β Annealing on the Microstructures and Mechanical Properties of TC18 Alloy (1235537)

Chaohua Li, Weiwei Zheng, Feng Zhang, University of Science and Technology Beijing, China

TC18(Ti-5Al-5Mo-5V-1Cr-1Fe) titanium alloy is a new type of α+β high strength titanium alloy. The strength of the alloy after annealing is 1100MPa, which is one of the highest strength titanium alloys in the annealed state. The microstructure characterizations such as the size, content and distribution of the constituent phases are very sensitive to the heat treatment and processing parameters, which directly affect the final mechanical properties of the alloy. In this paper, microstructure characterizations after a series of different annealing heat treatment processes were quantitatively investigated by using SEM, and TEM, and the mechanical properties at room temperature corresponding to different microstructures were tested. The results showed that during the primary annealing process, the volume fraction of α plates increased with the decrease of the intermediate temperature and the increase of the holding time. The length of the α plates, the thickness of α plates in β grains and the width of the grain boundary α plates all increased with the holding time. Furthermore, the width of the grain boundary α plates was always greater than the thickness of α plates in β grains. Increasing the intermediate holding time of the primary annealing could only improve the strength slightly and had almost no effect on the plasticity. During the secondary annealing, the secondary acicular α phase precipitated from the metastable β phase retained during the primary annealing process, the annealing twins appeared in the α plates formed during the primary annealing process, the thickness of the α plates decreased and spheroidization of α phase occurred simultaneously. The volume fraction of α plates had the greatest influence on tensile property and fracture toughness. The larger the volume fraction, the higher the strength and the lower the crack growth rate. Fine secondary acicular α phase could significantly improve the strength, and had little influence on the fracture toughness, but led to obvious decrease of the plasticity. Therefore, the mechanical properties of the TC18 titanium alloy could be improved by controlling the intermediate holding temperature in the primary annealing process.

C3-2: Effect of Strain Rate and Temperature on Compressive Behaviour of TiAlMn Alloy(1309252)

Lihong Su, University of Wollongong, Australia; Dong Ruan, Guoxing Lu, Swinburne University of Technology, Australia; Huon Bornstein, Defence Science and Technology Group, Australia

TiAl based alloys have been considered novel light-weight structural materials due to their advantages of low density, high specific strength, good oxidation resistance and creep resistance at elevated temperature. This research investigates the compressive behaviour of Ti-45Al-8Mn alloy subjected to compressive loading at various strain rates and temperatures.

Room temperature compressive stress strain curves showed characteristics of a typical compression curve of brittle materials showing marked failure. At a strain rate of 0.001/s and room temperature, the specimen fractured at a strain of approximately 30% and shattered into pieces. Cross-sectional microstructure and fracture surface characterisation indicated that there was no plastic deformation for the tests at room temperature. At 600˚C and the strain rate of 0.001/s, the stress of the specimen was higher than that at the room temperature. Obvious plastic deformation could be observed in the specimen as well as large amount of micro cracks. At 800˚C and above, the shape of the stress strain curve showed characteristics of compression curve of ductile materials. Microstructure observation indicated occurrence of plastic deformation and phase transformation. Fracture was not observed for the tests at 600˚C and above.

At high strain rates above 1000/s, the flow stress increased compared to the low strain rate for the tests at room temperature, and it increased with increasing strain rate, which indicates that there was a slight strain rate hardening effect. At elevated temperature and high strain rate, the flow stress decreased compared to that at room temperature with similar strain rate levels and the stress reduced with increasing testing temperature.

It can be concluded from the results that the Ti-45Al-8Mn material is intrinsically brittle. At 600˚C, the material showed higher stress and better ductility than room temperature, indicating that the material may be more suitable to be used at elevated temperature.

C3-3: Lattice Deformation and High Temperature Oxidation Behavior of Ti-6Al-4V Alloy Powders Prepared by Heat Treatment under Ar+H_2 Atmosphere(1232123)

Gye-Hoon Cho, Jung-Min Oh, Jae-Won Lim, Chonbuk

National University, South Korea

Developments in the 4th industry and 3D printing technology have raised interest in powder metallurgy products. The advantage of powder metallurgy is that can easily produce high melting point metallic products. In addition, it is possible to decrease waste of raw materials by reducing scraps occurrence. Accordingly, the use of titanium and titanium alloy powders is also gaining attention. Ti and Ti alloys are one of materials used throughout the industry because of its high strength and excellent corrosion resistance. In particular, they are a major material for artificial bones and implants due to their biocompatible properties. Recently, because of the development of 3D printing technology, complex shapes of artificial bones can be processed. As a result, the demand for Ti and Ti alloy powders is increasing significantly.

The problem of powder metallurgy is that the mechanical properties of final products are lower because the density is not perfect. In addition, the oxygen contents of powders has a large effect on the final density. Therefore, recent trends are toward lowering oxygen contents and increasing the density of final products.

In the present work, new heat treatment that dissolve hydrogen was developed without forming hydride. Dissolved hydrogen will have a good effect on sintering properties such as oxidation resistance and green density. In the experiment, commercially available Ti-6Al-4V alloy powders were used. The powders were annealed using tube furnace in argon atmosphere at 700˚C and 900˚C during 120min. Hydrogen was injected temporarily during argon annealing to dissolve hydrogen, and continuously a dehydrogenation process was performed in argon atmosphere. The prepared powders were analyzed by X-ray diffraction and gas analysis, and confirmed that hydrogen was dissolved. Hydrogen was first solubilized on the beta phase and expanded the beta phase's cell volume. The dissolved hydrogen contents were determined by the temperature. TGA analysis was carried out to evaluate the oxidation resistance, and it was confirmed that hydrogen dissolved Ti-6Al-4V alloy powders improved oxidation resistance than the raw material.

C3-4: Influence of Cutting Oil on the Scraps During Ti-30Fe Ingot Preparation(1232126)

Suhwan Yoo, Chonbuk National University, South Korea

Mechanical and chemical properties of titanium alloys with high strength, stiffness, toughness, low-density and good corrosion resistance at various temperatures enable weight reductions in aerospace structures and other high performance applications. Ti is used in not only aerospace but also daily products like glasses frames, golf club, tennis racket, bicycle and wrist watch. Furthermore Ti is used in implant. Despite having great properties, it has difficult processability. Because Ti is hardly formable, it generates a lot of scraps during processing. Various researches are under way to recycle this scraps. As a part of this, the use of Ti deoxidation additive in steel making process can be mentioned. The Ti deoxidizer is used as a substitute which can avoid the effect of nitrogen aging of Al deoxidizer in the steel making process. The Ti deoxidizer used at this time is required to be grade B or higher according to the ASTM standard. In this paper degreasing process of Ti scraps and making CP Ti-30Fe ingots are discussed. For degreasing process, the variables of solution concentration and temperature were set for optimization of cleaning conditions. And then, in order to analyze the influence of cutting oil adhered to Ti scraps, Ti scraps were degreased with NaOH with Tetrasodium Pyrophosphate(TSPP). To further see the influence of stirring, Ti scraps were agitated in NaOH aqueous solution and TSPP as additive to variable to remove cutting oil by washer. Two types of washers are used: Ultra-sonic washer, simple stirring washer. CP Ti scraps and CP Ti scraps degreased in NaOH with TSPP with washer were investigated. Thereafter, a Ti-30Fe ingot was prepared by washed Ti scraps and pure electrolytic iron. The washed Ti scraps and pure iron are melted in vacuum arc melting furnace. The influence of cutting oil on the Ti scraps during Ti-30Fe ingot preparation was investigated.

C3-5: Influence of Mo to Fe Ratio on Heat-Treatment Effects in Ti-Mo-Fe Alloys(1234058)

Masahiko IKEDA, Masato Ueda, Yuka Sakai, Kansai University, Japan

Iron (Fe) is a typical impurity in titanium (Ti) and its alloys, and its maximum acceptable concentration is limited because of its detrimental effect on the mechanical properties of the alloy. However, Fe has recently been adopted as an alloying element for Ti due to its lower cost than other beta stabilizing elements and its high abundance. In beta Ti, Fe undergoes abnormally fast diffusion, in contrast to the typical beta stabilizing element molybdenum (Mo), whose diffusion coefficient is lower than other beta stabilizers at the same temperature. Since the diffusion coefficient for Fe is almost two orders of magnitude greater than that for Mo, it is of interest to study the effects of co-addition of both Fe and Mo during heat treatment. Therefore, the Fe and Mo content was varied while keeping the ratio of the number of valence electrons to the number of atoms fixed, and the effects of heat treatment on these alloys was investigated based on electrical resistivity, Vickers hardness, and X-ray diffraction (XRD) measurements. The XRD results indicated that in all heat-treated specimens, only the beta phase was present. The resistivity at both room temperature and liquid nitrogen temperature decreased with increasing Mo content, as Fe was substituted by Mo. The temperature dependence of the resistivity was negative. During aging tests, the time until the initiation of precipitation increased with increasing Mo content. Details of the heat treatment results will be presented at the conference.

C3-6: Optimization of both Composition and Manufacturing Process for α-Type Titanium Alloys and Their Characterizations(1222462)

Xilong Ma, Kazuhiro Matsugi, Zhefeng Xu, Yongbum Choi, Hiroshima University, Japan; Jie Hu, Xingang Liu, Hao Huang, Yanshan University, China

α-type titanium alloys which contain α stabilizers such as aluminum, zirconium and tin were widely used for chemical and cryogenic applications, as well as building materials of offshore drilling. New designed α-type titanium alloys were proposed with both electron parameters (bond order (Bo) and d-orbital energy level (Md)). The contour lines estimating the ultimate tensile strength (σ_{UTS}) values could be indicated by connecting the reported α-type titanium alloys in the Bo-Md diagram. The practically alloy Ti-5Al-2.5Sn showed 750MPa and 15% in the σ_{UTS} and fracture strain (ε_f), respectively. These values and its hot corrosion resistance were used as objectives. New designed alloy Ti-5Al-4Zr-3.6Sn (Md: 2.422, Bo: 3.430) and Ti-6Al-1.7Sn-1.3Zr (Md:2.422, Bo:3.487) were proposed on the basis of the contour lines. The Ti-6Al-1.7Sn-1.3Zr alloy had both same Bo and Md values as those of reference alloy Ti-5Al-2.5Sn. Three α-type alloys were produced by the cold crucible levitation melting (CCLM) technique as the single manufacturing process, which cooling solidification rate were controlled by adjusting its magnitude of current. The single α phase with size of 800μm was identified in three α-type alloys. The homogeneous microstructures were observed in three α-type alloys, which was attribute to the effect of CCLM. The σ_{UTS} and εf values were shown on Ti-5Al-4Zr-3.6Sn alloy: 801MPa, 16% and Ti-6Al-1.7Sn-1.3Zr alloy: 695MPa, 15%, respectively. Their values were improved compared with those of reference alloy: 598MPa, 15%. In contrast, the hot corrosion results at as-cast condition showed the ratio of weight loss of Ti-5Al-4Zr-3.6Sn, Ti-6Al-1.7Sn-1.3Zr and Ti-5Al-2.5Sn were 3.86%, 4.15% and 4.85%, respectively. The results of σ_{UTS}, ε_f and hot corrosion resistance were achieved by new designed alloy Ti-5Al-4Zr-3.6Sn, which meant the new designed alloy Ti-5Al-4Zr-3.6Sn was a possible potential material even at as-cast condition for practical applications.