W-01
3D Printed Porous Ti-6Al-4V/PEEK Composite Implants
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A New porous Ti-6Al-4V/PEEK composite implant was studied. Surface modification of PEEK substrate surface was used by arc plating and plasma spray coating to deposit a Ti-6Al-4V interface layer. Then porous Ti-6Al-4V scaffold on the metal coated PEEK surface was formed by 3D printing method. The porous Ti-6Al-4V scaffold can improve bioactivity of PEEK, and enhance the bone fusion effect. The interfacial microstructure and bonding strength of the Ti-6Al-4V/PEEK hybrid implant are evaluated. The experimental results show that Ti-6Al-4V layer with a thickness about 300 \( \mu \)m were deposited on the PEEK substrate by using plasma spray coating. The PEEK interface is not damaged due to the surface temperature of substrate was maintained below 120 °C. And, subsequent 2 - 4 mm thick porous Ti-6Al-4V layer was formed on this hybrid structure by selective laser melting process. The tensile shear strength of bonding interface between Ti-6Al-4V metallic layer and PEEK substrate has reached over 25 MPa. The FE-SEM micrographs show those Ti-6Al-4V metallic layers on PEEK substrate have a pore-free interfacial microstructure and a good adhesion. The biocompatibility result of Ti-6Al-4V/Ti64-PEEK hybrid implant is also discussed.

W-02
Effect of processing parameters on a Ti-45Al-2Cr-5Nb alloy processed by selective laser melting: microstructure, phase and nanohardness
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This work presents a comprehensive study on the processing parameters on the microstructure development, phase evolution and nanohardness of a TiAl alloy, Ti-45Al-2Cr-5Nb (at.%), processed by selective laser melting (SLM). The experimental results show that when increasing the laser power from 250 to 350 w, the crystallographic texture varied from a strong (0001) orientation to a combination of (0001), (10-11) and (11-21) orientations, as the scanning speed from 500 to 800 mm/s, the average grains size decreases from 7.11 \( \mu \)m to 5.43 \( \mu \)m, whereas the crystallographic texture showing a combination of (0001), (10-11) and (11-21) orientations basically remains unchanged. The SLM-processed TiAl alloy is dominated by high-angle (\( > 15^\circ \)) grain boundaries (HAGBs) and the contents of HAGBs decrease from 91.6% to 86.1% when the laser scanning speed varies from 500 to 800 mm/s. The \( \alpha_2 \) phase decreases while the \( \gamma \) and B2 phases increase with increasing the laser scanning speed. Moreover, the phase evolution mechanism in the SLM-processed TiAl alloy can be described as follows: transforms to and , and then the residual B2 and the incompletely transformed \( \gamma \) phase randomly distributed in the \( \alpha_2 \) phase matrix. The nanohardness of the SLM-process TiAl alloy increases from 7.90 ± 0.32 GPa to 9.49 ± 0.46 GPa with increasing laser scanning speed from 500 to 800 mm/s, which is much higher than those of traditionally manufactured counterparts, such as casting parts (4.98 ± 0.10 GPa) and TiB2 reinforced TiAl alloy fabricated by roll bonding (6.73 GPa). With the increase of laser scanning speed from 500 to 800 mm/s, compression properties of the SLM-process TiAl alloy increases from 829.41 ± 24.88 MPa to 1216.16 ± 36.48
Fiber laser had been widely applied in additive manufacturing, especially for the metallic materials. The new advances of IPG fiber laser was introduced in this article, such as, the ultra-good beam quality, the power output stability, the high wall-plug efficiency, etc., and the benefits resulted from these characteristics. Also, a high power green laser, which is the new product of IPG Photonics company and could be possibly the power source of the next generation laser additive machine, was introduced. Due to its shorter wavelength, the spot size can be smaller compared with current YLR lasers and the absorption rate to metallic materials can be much higher. Therefore, finer structure and faster fabrication rate can be achieved with the green laser.

This study focuses on heat treatment of Ti6Al4V tensile specimens that had been fabricated via selective laser melting (SLM). The resultant microstructure and mechanical behavior at room temperature was investigated in detail. Heat treatment were conducted between 600°C and 900°C. It was found that the SLM fabricated samples consisted of long columnar original beta grains together with parallel acicular alpha' martensitic structure on the side view, and fully equaxed beta grain pattern on the top view. Heat treatment did not completely disrupt the layered structure, however, it leads to the acicular alpha' martensite decomposing into alpha platelet distributed in metastable beta matrix. After heat treatment, an increase in elongation was observed for tensile samples in both horizontal and vertical directions, inducing more ductile like fracture morphology. Meanwhile, the heat treatment reduces the yield strength due to the recovery process such as the decreasing of dislocation density and rearrangement of these dislocations in the grain boundaries.

Laser solid forming (LSF) 2Cr13 stainless possess significant engineering value. It is fundamental to clear the microstructure characteristics and under their evolution mechanism. In this paper, a series of deposits of different dimensions were prepared. With optical microscopy (OM), scanning electron microscopy (SEM) and transmission electron microscopy (TEM), the microstructures of the deposits
were characterized. Based on the temperature history, the solidification and solid transformation were analyzed to investigate the microstructure evolution mechanism. The single-track and single-layer deposit consists of dendritic martensite and interdendritic austenite. There exists the skeleton $\delta$ ferrite in the center of the dentrite. The single-wall and bulk deposit possess the similar microstructure. In the lower part, the M23C6 type carbides disperse along the columnar grains boundary. The substrate mainly consists of martensite. In the middle part, no carbides can be observed. In the upper part, the microstructure becomes the similar to that of the single-track deposit except the increased primary dentrite arm space. The microstructure of single-track is determined by the solidification. Due to the microsegregation, the Cr and C enrich in the interdendritic location, which result in the formation of interdendritic austenite. The solidification path is $(L \rightarrow \delta) \rightarrow (L + \delta \rightarrow \gamma) \rightarrow (L \rightarrow \gamma)$. As for single-wall and bulk deposit, the microstructure is determined by the transformation of the austenite during the subsequent heat cycle after solidification. Due to the heat accumulation, the substrate temperature increases above the $Ms$ temperature rapidly. The martensite transformation cannot therefore occur after solidification. Owing to the delay of the austenite transforming to the $\alpha$ ferrite, only carbides can precipitate when the depositing time is not long enough. After deposition, the austenite will transform to the martensite. As the undergoing time decreases from bottom to top, the amount of precipitated carbides also decreases.

W-06
Tailored gradient interface and its function on mechanical properties of WC reinforced Inconel 718 composites using selective laser melting
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The Selective Laser Melting (SLM) process was applied to fabricate WC particles reinforced Inconel 718 composite parts. The laser energy linear density ($\eta$) played an important role in determining the microstructure and properties of the SLM-processed WC/Inconel 718 composites and the effects were investigated. At the applied $\eta$ of 303 J/m, a near dense full part with a uniform particle distribution was obtained. A tailored gradient interface was formatted between the WC particles and the matrix with a composition of $(W, M)_C_3$ ($M$=Ni, Cr, Fe). In the meantime, a diffusion layer with a composition of $(W, M)_C_2$ ($M$=Ni, Cr, Fe, Nb) was detected outside the gradient interface, showing a slight increase amount of Ni, Cr, Fe and decrease of W and C as well as an additional strong carbide-forming element Nb. With the increase of the used $\eta$, the mean thickness of the gradient interface increased and the morphology changed continuously from an insufficient to a regular, refined and then a coarsened state. When the optimal $\eta$ of 242 J/m was utilized, the microhardness of the sample reached as high as 390.3 HV0.1 and the wear performance was also the most excellent. A considerably low coefficient of friction (COF) of 0.38 and wear rate of $2.5\times10^{-4}$ mm$^3$N$^{-1}$m$^{-1}$ were achieved at a $\eta$ of 242 J/m. The wear mechanism varied from abrasive wear to adhesive wear with the enhancement of the applied $\eta$. A relationship between the microstructure and properties were illustrated.

W-07
Solid-state Additive Manufacturing by Cold Spraying: Current key Issues, Possible Solutions and
Prospectives
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High performance metal additive manufacturing (AM) has been overwhelmingly investigated in recent years because of its unique advantages over the traditional manufacturing processes. AM has been widely used in forming complex components of Ti alloys. However, for other nonferrous alloys such as Al alloys, Mg alloys and Cu alloys, it seems not so good because of its melting nature during processing by laser, electron beam, and/or arc. Cold spraying (CS) has been widely accepted as a promising solid-state coating technique in last decade for its mass production of high-quality metals and alloys coatings, and/or metal matrix composites. It has been recognized now as a useful and powerful tool for AM, but the related research work was just started. This review will summarize the literature on the state-of-the-art and problems for forming Al, Mg or Cu alloys parts, especially high-strength alloys.

W-08
The forming mechanism during the titanium alloy 3D printing using wire-arc surfacing welding
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Wire-arc surfacing welding is a kind of 3D manufacturing technology with high-efficient and low cost. Titanium alloy is a kind of metal with high strength, good corrosion resistance and heat-resistant, which make its widespread use in aviation and aerospace industry. This paper focus on the processing-microstructure-property relationship of titanium wire-arc surfacing welding. Mechanical properties, residual stress and distortion of the parts were studied, which gives the fundamental data for sequential studies.

The main research contents are as follows:
1. Establishing the additive manufacture system of wire-arc surfacing welding based on the industrial robot. The robot system could automatically adjust the welding space position and process parameters to guarantee the quality of 3D forming and the stability of the manufacturing process.
2. Process parametric study
   (1) Studying the height consistency of finished product. We mainly research how the welding path, material transfer and arc shape influence the height during multi-layer & multi-pass welding. And in the welding process, for ensuring the quality of welding, we prevent weld defects such as hydrogen, oxygen, carbon and nitrogen into the welding parts.
   (2) Researching the regulation during additive manufacture. The accumulation of heat is a big problem during multi-layer& multi-pass welding. Too much heat not only makes product grain size grew up quickly, this will influence the final parts performance, but also causes the collapse, and this will influence the forming accuracy. In order to prevent collapse and control precision, we study and control the interlayer temperature in additive manufacture process.
   (3) The relationship between the welding current, welding speed and arc voltage and the weld width and layer thickness.
In the process of multi-layer& multi-pass welding, the weld width and thickness of layer are two important parameters. So we study the change rule of the welding current, welding voltage and welding speed, and mainly research the change of the three parameters how to influence the weld width and thickness of layer. The formation
of molten titanium alloy and liquid pool movement is also a very important research content during multilayer multi-channel welding. Through the above content research, The titanium alloy’s part’s dimensional accuracy is assured by control the size of welding pool.

3. Evaluation of the titanium alloy 3D parts
The static and dynamic mechanical property is studied by tensile and fatigue test. The microstructure is observed to reveal the defects such as included slag, pores and cracks. The evolution of the grain structure along the height is studied combine with the overall performance.

Titanium is a strategic emphasized structural metal which gained huge concern of many countries. A lot of research and development is focus on titanium alloys. This study focus on the forming mechanism during the titanium alloy 3D printing using wire-arc surfacing welding. The high-productive and high-quality titanium alloy 3D printing parts is based on a robotic arc welding system.

W-09
Microstructural Evolution Mechanism and Properties of Laser Rapid Prototyping Zr-based Bulk Metallic Glass Composites
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Objective: Recent advancement in bulk metallic glasses (BMGs), whose properties are usually superior to their crystalline counterparts, has stimulated great interest in their production and application. While a great deal of effort has been devoted to this field, the fabrication of BMGs with large cross sections has remained an alchemist's dream because of the limited glass forming ability (GFA) of these materials. The small molten pool deposition characteristic with point by point in laser rapid prototyping (LRP) makes this technology be able to be used to prepare BMGs without the limitation of critical cooling rate and critical casting diameter. This can further promote the application and development of BMGs.

Method: In the present study, the microstructural evolution during pulsed laser deposition of Zr-based metallic glass was particularly characterized using the state-of-the-art facilities. The underlying deformation mechanisms related to the improvement of strength and ductility were systematically investigated by focusing on the interaction between nanocrystallines/ductile dendrites and deformation units, i.e. shear bands, dislocations or twins.

Results: The nanoindentation creep resistance improved significantly, and strain hardening behaviors were also observed.

Conclusions: The improved nanoindentation creep resistance and strain hardening behaviors were attributed to both the initiation of the deformation bands or twins in the dendrites and the suppression of the highly localized shear deformation in the nanocrystallines-included amorphous matrix. Based on the present model and experiment results, LRP may be a promising way to fabricate high-performance BMG composites without size and shape limit.

W-10
Study of Microstructure and Properties of Ag/SnO2 Produced by Selective Laser Melting
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Ag/SnO₂, as a promising and environmentally friendly electrical contact material, is widely studied and applied in different low-voltage apparatus. But the poor distribution of Ag/SnO₂ produced by the methods of powder metallurgy or internal oxidation limits its application. In this work, selective laser melting (SLM), as one of the additive manufacturing technologies, is applied to prepare the Ag/SnO₂ materials. The effect of laser power, scanning speed and shielding gas on the microstructure and properties of Ag/SnO₂ was studied. The reinforced SnO₂ phase was characterized by X-ray diffraction and Transmission Electron Microscope. The microstructure was observed by Scanning Electron Microscope. The results indicated that homogeneous microstructure, high density and hardness can be obtained by SLM.

W-11
The Development of Electron Beam Selective Melting for TC4-TiAl gradient structure
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Since TC4 has excellent mechanical properties with high strength and good plasticity at room temperature, while Ti₄₇Al₂Cr₂Nb has excellent performance at high temperature, but low plasticity in room temperature. A TC4/Ti₄₇Al₂Cr₂Nb gradient structure might provide a new concept of functional gradient material for turbo impeller, in which the blade is made by Ti₄₇Al₂Cr₂Nb to suffer the high temperature gas and the root is made by TC4 to resist the complex and high stress in relative lower temperature zone.

Method: Electron beam selective melting (EBSM) is an additive manufacturing technique that can directly fabricate conductive material parts by the electron beam selectively scanning and melting the powder bed layer by layer. A novel EBSM system for fabricating gradient structure with dual metal materials has been developed with a new powder supply device, driven by vibration, to provide the precise powder delivery capacity, by which the mass of powder and the mixture ratio for each layer could be controlled and varied gradually.

Results: TC₄(Ti₆Al₄V) powder and TiAl(Ti₄₇Al₂Cr₂Nb) powder were used to build the gradient structures, which changed from pure TC4 or pure Ti₄₇Al₂Cr₂Nb to TC₄+Ti₄₇Al₂Cr₂Nb mixture, and pure TC4 to pure Ti₄₇Al₂Cr₂Nb through the gradient interface with varied mixture ratio of TC4 and Ti₄₇Al₂Cr₂Nb powders. The microstructures and chemical compositions were characterized by optical microscopy, scanning microscopy, and electron microprobe analysis. Results showed that the interface was about several hundred micrometers of thickness and free of cracks. The chemical compositions exhibited a staircase-like change within the interface.

Conclusion: Compared to SLM technique, EBSM can provide higher heating efficiency, higher temperature in building chamber and lower thermal residual stress. It has the potential to adapt more material, especially the brittle material, than SLM, and the capacity to build the Ti alloy – TiAl intermetallic gradient structure without crack.

W-12
Recycling and remanufacturing of 3D printed continuous carbon fiber reinforced PLA composites
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Low-cost manufacturing and recycling technologies for high-performance continuous fiber reinforced composites are very important to industrial applications. A novel 3D printing based fabrication process of continuous fiber reinforced thermoplastic composites (CFRTPCs) was proposed. Continuous carbon fiber and PLA filament were utilized as reinforcing phase and matrix, respectively, and simultaneously fed into the fused deposition modeling (FDM) process realizing the integrated preparation and forming of CFRTPCs. When the fiber content of printed composite specimens reached 27%, flexural strength of 335MPa and modulus of 30 GPa were obtained. Recycling and remanufacturing strategy for 3D printed CFRTPCs was proposed to retrieve the carbon fiber and PLA matrix in the form of PLA impregnated carbon fiber filament, which could be reused as the raw material for CFRTPCs 3D printing process. Remanufactured CFRTPCs specimens exhibited a 25% higher bending strength than that of originally printed samples.

W-13
Numerical modeling of thermal behavior and microstructure evolution during laser powder deposition process
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Laser powder deposition is a very promising technique for fabricating complex metal components layer by layer. The complex thermal behavior during laser powder deposition process results in the complex microstructure evolution, which directly affects the final mechanical properties of the products. Numerical modeling offers a cost efficient way to better understand the related complex physics in laser powder deposition process. It helps to reveal the effects of processing parameters on the desired characteristics of deposition parts.

In this work, a heat transfer finite element model is coupled with a multi-phase-field model to predict the thermal behavior and microstructure evolution during laser powder deposition process. The thermal behavior during single-track and multi-track deposition process was simulated numerically by using a three-dimensional transient finite-element model [1], where deposition of material was modeled through activation of a new set of elements within each solution step. The deposition geometry was well predicted without assuming a prior shape. The influences of the scanning speed and laser power on the morphology and dimensions of molten pool were investigated. It is found that the molten pool height decreases with the increase in the scanning speed, while the increase of laser power results in the increase of molten pool size. The temperature history extracted from the macro simulation was then transferred to a micro region inside the mushy zone of the molten pool, where dendrite growth during solidification was simulated by the multi-phase-field model [2]. The effects of several process parameters on the solidification microstructures were investigated. Directional dendritic growth from the bottom of the pool was observed with various dendrite arm spacing and orientation depending on the location in the pool. The microstructure and the value of dendrite arm spacing obtained in simulation agree well with previous experimental observation.

W-14
Effect of Ti addition on mechanical properties and microstructure of Inconel625 during the laser solid forming processing
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During the processing of laser solid forming Inconel625 superalloy, because the Nb element segregates to interdentritic region, the low melting eutectic (IFN-gamma+Laves) forms and the solidification temperature range expands. The liquid film will be broken by high thermal stress during the thermal cycle processing, and the solidification cracking forms easily. The addition of Ti element will affect microstructure and mechanical properties of Inconel625 superalloy. Appropriate content (5wt%) of addition of Ti element can significantly reduce the solidification temperature range and effectively restrain solidification cracking. The addition of Ti element can form IFN-gamma'-Ni3Ti phase which is the main precipitation strengthening phase in superalloys and improve the mechanical properties of Inconel625.

**W-15**

**Investigation into Additive Manufacturing of Customized Ti6Al4V Bone Plate for Pelvic Fracture**

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In pelvic fracture operations, bone plate moulding is challenging and the operation time is long. To address this issue, a customized bone plate was designed and produced using selective laser melting (SLM) technology. This technology enables quick fabrication of a Ti-6Al-4V customized bone plate. The plate was clinically tested with the aim to improve the quality of fracture reduction and shorten the operation time.

The key steps of this study included designing the customized bone plate with input from a medical doctor, metal 3-D printing, and quality control of the customized bone plate. The production steps involved a vacuum heat treatment, surface post-treatment, pre-operative exercise, clinical application and evaluation.

The quality control studies of the SLM-fabricated customized bone plate ensured fabrication accuracy. Careful observations were taken on the effectiveness of attaching the complex curved surface. The joint surface of the bone plate is placed upwards to keep it from the support and to improve the quality of the joint surface between the customized bone plate and the pelvis. Heat conduction is enhanced during the SLM fabrication process by adding a cone-type support beneath the bone plate to prevent low-quality fabrication from poor heat conductivity of the Ti-6Al-4V powder. The residual stress is eliminated by exposing the SLM-fabricated titanium-alloy bone plate to a vacuum heat treatment. Results indicate that the bone plate has a hardness of HV 360- HV390, a tensile strength of 1000-1100MPa, yield strength of 900-950MPa and an extensibility of 8-10%. Hence, the fabricated bone plate meets mechanical property requirements for standard medical bone plates.

The titanium alloy bone plate was surface oxidized to reduce the release of metal ions within the body. Pre-operative experiments and exercises were performed using the oxidized bone plate and the ABC-made pelvic model.

Finally, the customized bone plate was clinically applied. The intraoperative C-arm and postoperative CT imaging results indicate that the customized bone plate matches the damaged pelvis 100%. The customized bone plate fixes the broken bone and guides pelvis restoration while reducing operation time to about two hours. Compared to the standard bone plate, fabricating the customized bone plate using digital design and metal 3-D printing technologies has enormous advantages. The customized bone plate matches the fracture fragments perfectly and eliminates the need for preoperative titanium plate pre-bending, thereby greatly reducing surgical wounds and operation time. Hence, the customized bone plate provides a minimally-invasive, high-precision and customized therapy for complicated pelvic and acetabular fractures.
**W-16**

The effect of heat treatments on anisotropic creep and low cycle fatigue properties of IN718 processed by selective laser melting

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The anisotropic creep and fatigue properties remain a big concern for the application of additive manufacturing in the critical components of aerospace and power generation equipments. In this presentation, the nickel-based superalloy IN718 samples were manufactured via selective laser melting (SLM) technology (EOS M280), with different orientations relative to building direction, to investigate the anisotropy of SLMed components. In addition, three variants of heat treatments were accepted, i.e. (1) solution + aging (SA) (2) homogenization + aging (HA) and (3) homogenization + solution + aging (HSA). The influence of sample orientation and post heat treatments are systematically investigated via creep and low cycle fatigue testing under 650°C. Together with the thorough examination of precipitate phases, microstructures, and fracture surface using OM, SEM, EBSD, EDX, TEM and X-ray analysis methods, the micro-mechanism and modeling were developed for the guidance of property optimization.

**W-17**

Deformation Behavior Studies on a Stainless Steel Fabricated by Selective Laser Melting Using In-situ Neutron Diffraction

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Objective: Additive manufacturing (AM) technology has been recently employed for application to a broad variety of industrial area, such as automobile, aerospace, and medical device due to the advantages of the fabrication of rapid prototype. As the AM technology provides alternative manufacturing capability, the microstructural stability and mechanical properties should be verified because those are directly related to safety as well as performance of the commercial products.

Method: Microstructural analysis and deformation behavior of 15-5PH stainless steel manufactured by selective laser melting (SLM) were studied. The SLM is one of the powder bed fusion methods of the AM. Two types of SLM specimens are prepared: 1) a flat type dog-bone specimen, in which the direction of powder building is perpendicular to the axial loading direction

2) a cylindrical dog-bone specimen, in which the direction of powder building is parallel to the axial loading direction. Both specimens were fabricated under the volume rate (a measure of build speed during laser exposure) of standard 1.8 mm\(^3\)/s. In-situ neutron diffraction experiment was performed to investigate the influence of manufacturing direction on deformation behavior of AM stainless steel using the Vulcan Engineering Diffractometer at Spallation Neutron Source of Oak Ridge National Laboratory. The AM specimens were deformed in uniaxial tension until a strain of 9% followed by unloading, and then reloaded up to a strain of 14.5%
followed by unloading again.

Results & Conclusion: Lattice strains, diffraction peak intensity, and full width at half maximum (FWHM) of various grain families were measured to understand the deformation behavior at the microstructural level. Strain partitioning and phase evolution between body-centered cubic and face-centered cubic were quantitatively investigated as a function of applied stress in the specimens. The variations of lattice parameter, phase fraction changes, and strain hardening mechanisms will be further discussed in the presentation.

**W-18**

**Effect of the microstructure characterization on electrochemical behavior of LAM Ti–6Al–4V alloy**

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Laser additive manufacturing (LAM) is a novel manufacturing technique in which metal component can be fabricated layer by layer. In this study, Ti-6Al-4V alloy was deposited by LAM process. Microstructure characterization have been investigated by optical microscope, scanning electron microscope and image-pro plus. The electrochemical behavior of the specimens with different microstructure characterization was investigated using linear sweep voltammetry, which in order to explore the electrochemical machinability of the LAMed Ti-6Al-4V alloy. The characterization of the macro-/micro-structure in different position of the specimens which fabricated with the change of the laser power could be observed. The macrostructure of interior was bulky columnar crystal grows along the deposition direction and the columnar crystals have a certain angle to the side wall at side of the deposited sample, while the top of the deposited sample may appear a certain thickness of equiaxed crystal layer. Meanwhile, the anodic polarization curves of different macro-/micro-structure were obtained, which revealed the electrochemical dissolution behavior of LAMed Ti-6Al-4V alloy with different macro-/micro- structure. The equiaxed crystal layer were easily to machining by electrochemical machining than the columnar crystal. The finer of the macrostructure and the homogeneous of the microstructure facilitated the electrochemical dissolution.

**W-19**

**Effect of the linear energy density on heat and mass transfer, thermodynamics and laser processability during additive manufacturing of Inconel 718 alloy**

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Selective laser melting (SLM) of the metallic powder commonly involves a complex non-equilibrium physical and chemical metallurgical processing, which includes multiple modes of heat, mass and momentum transition. To further investigate the thermodynamics, heat and mass transfer and surface quality within the molten pool during selective laser melting (SLM) Inconel 718 alloy, the transient three-dimensional powder-scale model has been established by finite volume method (FVM), taking into account the powder-solid transition, variation of thermo-physical properties and surface tension. The influences of linear energy density (LED) on the thermodynamics, heat and mass transfer, and resultant surface quality of molten pool have been systematically analyzed. It revealed that the LED played a crucial role in determining the terminally solidified surface quality of the SLM-processed components. As a reasonable LED of 221.5 J/m was used, a proper temperature gradient and the resultant surface tension tended to spread the molten liquid with a steady velocity, contributed to generating a
flat surface of the component and an attendant low average surface morphology. By contrast, as the LED exceeded 249.5 J/m, a considerable amount of molten liquid migrated towards the neighboring as-fabricated tracks with a higher velocity, resulting in a stacking of molten liquid and the attendant formation of the surface with a poor quality. The surface morphologies of the SLM-processed Inconel 718 components were experimentally obtained, which were in a good accordance with the results calculated by numerical simulation.

**W-20**

**Manufacturing of Large Components for the Aviation Using Laser Solid Forming**  
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Through laser solid forming (LSF), the parts with complicated geometry can be free-form near-net shaped rapidly without using the mold, meantime, the mechanical properties of the LSFed parts is equivalent to those of the wrought. These features make LSF be a viable and promising manufacturing technology for aviation industries, especially for the manufacturing of large components. In present work, the current applications of LSF technology on the aviation field are reviewed. The typical technical characteristics of LSF technology, the microstructure and mechanical properties of typical LSFed parts are analyzed, the effect of scanning pattern on the thermal/stress field during LSF of large components is introduced. Finally, the problems for the applications of LSF technology on the aviation field are discussed.

**W-21**

**Microstructure and tensile behavior of carbide ceramics particles reinforced iron matrix composites prepared by selective laser melting**  
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This study presents a study of iron matrix composites reinforced by carbide ceramics particles fabricated by selective laser melting. The effect of processing parameters and ceramic content on the microstructure and properties were investigated in this study. The reinforced carbide ceramics particles phases were characterized by X-ray diffraction. Microstructure was observed by Scanning Electronic Microscopy and Transmission Electron Microscope, it was found that the grain size decreased significantly by the addition of carbide ceramics particles. The tensile behavior of iron matrix composites was tested by Zwick material testing machine. Compared to the SLMed unreinforced iron samples, the carbide ceramics particles reinforced iron matrix composites exhibits much higher tensile strength.

**W-22**

**Thermo-mechanical analysis on the process of additive manufacturing**  
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The Additive Manufacture (AM) attracts more and more attentions of research institutions as well as enterprises. However, the overall properties of the products provided by Additive Manufacture have not match the promising
demands. Mathematical description was developed on the thermo-mechanical phenomena arise in Selective Laser Sintering (SLS) based Additive Manufacture. Finite Element Model (FEM) was established to simulate the physical process of the additive manufacturing of typical titanium structure by SLS. Temperature evolution and phase change are obtained by numerically solving the heat conduction equations involving phase changing of materials. Displacement, stress history and residual stress are achieved by solving the elastic mechanics equations with corresponding boundary conditions. The characteristics of the residual stresses in the structure are discussed to predict the performance of the finished structure.

W-23
Microstructure and mechanical properties of laser solid formed 30CrMnSiNi2A steel
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Microstructure and mechanical properties of laser solid formed 30CrMnSiNi2A steel were investigated. The as-deposited microstructure was inhomogeneity and presented the tempered martensite laths, the martensite laths with a small amount of bainite, and the mixture microstructure of martensite laths and bainite from the bottom to the top of the deposits. The size of martensite laths also increases gradually from the bottom to the middle-upper of the deposits. After heat-treatment of 900℃ 1h/oil quenching(OQ)+200℃ 1h/air cooling(AC), the microstructure was refined and uniform, and mainly consisted of the mixture of tempered martensite, bainite and retained austenite. In addition, the hardness showed a slightly inconsistency from the bottom to top of the as-deposited 30CrMnSiNi2A steel, and there was a slightly lower at the middle-upper of deposits than that of the bottom. The hardness in the heat treated deposits tended to be uniform and showed significant increase than that in the as-deposited 30CrMnSiNi2A steel. Tensile strength and yield strength of the as-deposited 30CrMnSiNi2A steel were much lower than the wrought standard. Through heat treatment, the tensile properties of laser solid formed 30CrMnSiNi2A steel were improved significantly and reached the wrought standard, but its reduction of area is slightly lower than that of the wrought.

W-24
Comparison of Microstructure and Mechanical Properties of Aluminum Components Manufactured by CMT
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This paper presents an investigation on the microstructure and mechanical property of Al-alloy parts made by using additive manufacturing based on CMT(Cold Metal Transfer) welding technology. With the same 3D model and process parameters, a set of hollow cylindrical parts with 80 layers were built up using 2319,4043,5356 aluminum wire, respectively. Then their microstructure, tensile strength, and hardness were tested and analyzed comparatively. It is found that the microstructure of parts made by 2319 wire and 4043 wire are mainly columnar crystal, while in the 5356 wire made parts, the element Mg mainly exists in the form of solid solution in the α-Al asprecipitated phase of Al3Mg2, which would contribute to improve the mechanical properties of the parts through solid solution strengthening mechanism. The tensile strength of the part made by using 5356 wire is the highest, and the strength in the welding direction is higher than that in the vertical direction. The elongation of the part made from 4043 aluminum wire is the highest. Its longitudinal elongation is measured to be 19.5%. No obvious
difference in the hardness between the interlayer and the fusion zone was observed, and the average hardness is measured at 82.3HV0.2. Ultrasonic method was also used to measure the Young's modulus of the additive manufactured parts. The longitudinal propagation velocity of ultrasonic wave in three kinds of materials is greater than that of surface wave. The Young's modulus measuring results were accordant with the results obtained by the mechanical property testing, and the error is within 3%.

W-25
The tensile deformation behavior of 50%LAMed IN718 superalloy with a non-uniform microstructure
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Laser Additive Manufacturing (LAM) technology has been used to fabricated the 50%LAMed Inconel 718 superalloy (i.e. the laser deposited zone and the substrate zone occupied 50% volume fraction respectively along the tensile direction) in the wrought substrate. The tensile deformation behavior was investigated by using Digital Image Correlation (DIC) method in this paper. The results showed that the train was focused in the laser deposited zone leading to the concentration of the plastic deformation. Unlike the wrought specimen with uniform microstructure, the transformation of the maximum strain region was not observed in the 50%LAMed specimen with non-uniform microstructure. Meanwhile, hard and brittle Laves phases were the main nucleuses for the formation of microscopic holes because of the concentration of strain. The failure mechanism of 50%LAMed Inconel 718 was microscopic holes coalescence ductile fracture.

W-26
Optimization of interpass temperature and heat input for wire and arc additive manufacturing 5A06 aluminium alloy
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Wire and arc additive manufacture (WAAM) is an effective rapid prototyping technology for near net shaping large scale metal components at low cost, which takes wire as raw materials and electric arc as heat source. It builds 3D parts in layer up layer fashion according to "dispersion-deposition" method. So each previous layer is a subbase for subsequent deposition. During the first twenty layers deposition, heat accumulation progressively increases, and heat conduction to substrate becomes worse and worse with the parts "growing tall", they jointly vary thermal boundary condition of molten pool significantly during the continuous forming process, which is defined as transition stage. Two phenomena are usually observed in transition stage, one is undulate surface. The other one is inconsistent cross sectional dimensions, i.e. layer height and width variation. Depositing on which, the subsequent layer would retain their morphology features, and finally resulting in large surface waviness. How to regulate the deposition in this stage so as to achieve smooth and consistent layer appearance is the main theme in this paper.
Interpass temperature (including substrate temperature, which can be seen as the root pass temperature) is selected as controlled variable to avoid undulate surface appearance, which is identified as effective method by conducting a series of experiments on the effect of interpass temperature on layer appearance. Trail and error method is still a much more common way used to decide a suitable interpass temperature now, although it is usually tedious and troublesome. To facilitate the optimization process of interpass temperature, a theoretical model is developed on
basis of Fourier law of heat conduction and energy conservation. According that a matched interpass temperature to heat input at the arc striking position is obtained, then the heat input is also regulated according to heat accumulation. This theoretical model is verified valid to regulate the shaping deposition process by manufacturing a 5A06 aluminium alloy wall.

W-27
An investigation on additive manufacturing of copper bulk by using cold spraying
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Additive manufacturing (AM) has been widely used to form structural components layer-by-layer. As an emerging solid-state spray technology, cold spraying (CS) is considered as a huge potential AM process for its unique advantages such as the eliminations of oxidation, phase transformation, decomposition, grain growth. Up to now, not only metal materials but also cerments and ceramic materials have been sprayed by CS. In this study, the AM copper bulks were deposited by CS. The microstructure and mechanical properties including tensile strength, microhardness and fractography were investigated in as-sprayed and annealed conditions. The results showed that after annealing, recrystallization happened making the severe defomed grains replaced by the distortionless grains, also the interfaces between particles became un conspicuous due to atom diffusion. In addition, compared with the as-sprayed bulk, the tensile strength increased by 34.2% while the microhardness decreased by 43.6%. For the as-sprayed bulk, the fracture occurred between the interfaces of particles and no dimples can be observed, indicating a brittle de-cohesive rupture. On the contrary, for the annealed bulk, uniformed dimples were found at the fracture surface, indicating a plastic rupture of micro-void coalescence.

W-28
Solid-solution Phase Transformation Behavior under Instant Severe Heating/Cooling Cycles during Laser Additive Manufacturing for Large Titanium Components
Haibo Tang;
Beihang University

W-29
Research Progress of Special Materials and Equipment for Laser Additive Remanufacturing
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Every year there are a large number of parts and components wasted and scrapped due to failure in manufacturing. Laser additive remanufacturing is a kind of repair technology because of high performance and high efficiency. However, the matrix material, failure position and performance requirement of the parts are not the same, resulting in the large differences in demand among the remanufacturing powder composition, laser type and repairing processing. Therefore, a series of special materials, the special equipment and the matching processing need to be designed to achieve high efficiency, high-quality for remanufacturing.

In this paper, the special alloy powder system for anti-cavitation, anti-high temperature and high wear-resistance by independent research will be introduced. Meanwhile, two types of laser additive remanufacturing systems with low power portable and high power modular features are developed according to the special requirements of
on-site remanufacturing. Matching with the special alloy powder and intelligent laser remanufacturing processing, the laser additive remanufacturing equipment can perform flexible movement, rapid assembling and on-site repairing with high quality and high efficiency. Therefore, the risk of return-to-maintenance of large equipment component with high added value can be reduced and the remanufacturing efficiency can be improved greatly.

W-30
Physical mechanisms for process and performance control during laser additive manufacturing of Al-based composites
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College of Materials Science and Technology, Nanjing University of Aeronautics and Astronautics

W-31
Microstructure and mechanical properties of forming pure tungsten by selective laser melting
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Tungsten (W) and its alloys are receiving more attention for nuclear fusion devices and high-performance rocket nozzles, because of the high melting point, high strength, good thermal conductivity and high threshold energy for physical sputtering. Tungsten structural components were usually prepared by traditional powder metallurgy method. However, the complexity of components prepared by traditional powder metallurgy is difficult because of its high melting point (3420 °C). Selective laser melting (SLM), as a newly developed Advanced Manufacturing (AM) technique, is applied in lots of fields, especially in aeronautics and astronautics. Therefore, in this study, we investigate the effect of laser power (300W, 350W, 400W, 450W) on the microstructure and mechanical properties of pure tungsten fabricated by selective laser melting, for aerospace applications. As the laser power (P) increased, density was enhanced and then flattened, pore of the material changed from the small hole disappears and big hole increases to big hole separate and shrink.

W-32
Selective-Laser-Melting, Relative density, Surface roughness, Microstructure, Mechanical properties
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Titanium alloys such as Ti-6Al-4V (TC4) are promising candidate materials for body implants due to their superior biocompatibility, excellent mechanical properties and low Young’s modulus which is more close to that of human bones than stainless steels. In this work, by powder-bed based Selective Laser Melting (SLM) process, TC4 samples with relative density of 93.8%-98.3% were additively manufactured through varying processing parameters including laser power (182-200 w), scanning speed (263-315 mm/s), and linear energy density (0.578-0.760 J/mm). Experimental results based on 3D surface profiler showed that increasing laser energy density can also effectively reduce the surface roughness of the as-built samples. Compared with the as-forged TC4 alloys, the tensile properties of the as-built TC4 has better mechanical properties, showing tensile fracture strength of 1196 MPa and elongation of 9.96%, both surpassing the corresponding international standards. In the SLM process, a large amount of residual stress stains in the parts because of the high temperature gradients, even
can cause cold crack. In the SLM process, the fast cooling rate leads to a microstructure which is composed of needle shaped martensite, α-Ti and β-Ti.

W-33
Investigation of electrochemical dissolution behaviors of Laser Solid Formed IN718 alloy and its solid-solution treatment state alloy at low current density in NaNO3 solution
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The laser/electrochemical hybrid precision forming technology has been recognized as an advanced processing method with the feature of high efficiency and high precision. Here, the electrochemical anodic dissolution behaviors of LSFed IN718 alloy and solid-solution treatment state alloy at low current density in NaNO3 solution were investigated and related to their microstructures. The electrochemical anodic dissolution behaviors were studied by (1) measuring the electrochemical anodic polarization curves of different sections in as-deposited and solid-solution treatment state samples, (2) analyzing the composition of the surface products, (3) observing the surface micro-morphology. The polarization curves showed that the corrosion potential of the as-deposited sample was less negative than solid-solution treatment, but its dissolution rate was faster than that of solid-solution treatment was found, which due to the Laves phase disappeared and dissolves into the γ phase. The XRD pattern showed the non-uniform dissolution of the as-deposited IN718 alloy and the uniform dissolution of the solid-solution state alloy. The micro-morphology demonstrated that the dendritic cores dissolved while the interdendritic regions remained of as-deposited samples and the grains boundaries dissolved preferentially and pitting corrosion occurred in solid-solution state alloy indicated that the atoms in grains boundaries were active and the element of Nb led to the pitting corrosion eventually. Furthermore, the solid-solution state alloy can avoid stray corrosion, indicating that it can increase the process precision to some degree. Therefore, the microstructures of anodic materials can control the electrochemical anodic behaviors significantly, which can influence the process of ECM.

W-34
A new additive manufacturing technology for metal powder
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Guangdong Institute of Materials and Processing

A new additive manufacturing technology for metal powder has been developed to prepare complex components, which takes full advantage of metal injection molding (MIM) and three dimensional printing (3DP). The feedstock was prepared by metal powders and binder in a kneader. The feedstock was shaped into complex components using 3D printer. The green components required debinding and sintering. Some complex components have been manufactured successfully by this technique. The density of 316L components manufactured by this method is 7.53g/cm³, the mechanical property is better than those by traditional Powder Metallurgy. Compared with MIM process, it has more excellent performance in complex components. Compared with general metal additive manufacturing process, such as selective laser melting, it is more suitable for mass production. The results of this additive manufacturing technique are encouraging, but several developmental steps such as improving dimensional accuracy are necessary for the future.
Investigation on microstructure of TiB$_2$/2024Al composite fabricated by laser solid forming
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State Key Laboratory of Solidification Processing, Northwestern Polytechnical University

TiB$_2$ particulate reinforced 2024Al composites was successfully fabricated by laser solid forming in-situ composite powder. The X-ray diffraction confirmed the formation of TiB$_2$, Al$_2$Cu, Al phase, and no large intermediate reactions Al$_3$Ti, AlB$_2$ can be traced. TEM demonstrated the precipitation of Al$_2$CuMg phase during the thermal cycles. Furthermore, the influence of TiB$_2$ particulates on nucleation and growth of the matrix was investigated. No certain orientation relationship between particulate and matrix can be found in the diffraction pattern and HRTEM showed that the bonding interface was clean. The particulates failed in heterogeneous nucleation in the solidification process and most of them with a range size between 150nm and 450nm was distributed along interdentrite, while the matrix performed strong epitaxial growth without suffering the effect of particulates and the width of columnar crystal quietly depended on the grain size of substrate.

Poster

Fabrication and Coloration Mechanism of CoAl$_2$O$_4$ Ceramic Pigment for 3D Printing
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Ceramic pigment, as the core part of the ceramic ink, is the key component of the ink color in the 3D printing process of ceramic products. At present, the color performance of ceramic pigments and these color stability after calcination still need to be improved. In this paper, cobalt aluminate (CoAl$_2$O$_4$) ceramic pigment powders were fabricated by sol-gel method. Compositions and morphologies of CoAl$_2$O$_4$ ceramic pigment powders were characterized by XRD and SEM. Effects of pH value, hydrolysis temperature, Co/Al ratio and calcination temperature on color properties of the CoAl$_2$O$_4$ ceramic pigment. The stability of CoAl$_2$O$_4$ ceramic pigment powders in aqueous ink was tested, and the color stability of the CoAl$_2$O$_4$ ceramic pigment at high temperature was discussed at last. The results show that the CoAl$_2$O$_4$ ceramic pigment is the typical spinel structure. The preparation process has a significant impact on the color stability of the CoAl$_2$O$_4$ ceramic pigment. The CoAl$_2$O$_4$ ceramic pigment with high saturation was obtained when the pH value is 2, hydrolysis temperature is 85°C, Co/Al ratio is 1:3 and calcination temperature is 1000 °C. The Zeta potential of the fabricated CoAl$_2$O$_4$ ceramic pigment powders in aqueous ink is -61mV, which has good dispersion stability. The saturation of the CoAl$_2$O$_4$ ceramic pigment was increased since the solid solution of the oxide in the spinel structure increased after high temperature treatment at 1300 °C. This ceramic pigment can be used in ceramic ink, which has good application prospect in 3D ink jet printing for ceramic products.

Characteristic of microstructure and hardness of GH4169 Superalloy fabricated by additive manufacturing using electron beam melting
In this paper, multilayer GH4169 Superalloy thin wall structure was prepared by additive manufacturing using electron beam melting. According to characteristics of electron beam rapid manufacturing technology, variation of microstructure and performance of the accumulation layer along the thickness direction was analyzed. The results showed that coarse columnar crystals in the formed GH4169 superalloy grew along the direction of the deposition, and the harmful Laves phase was found among the microstructure of the layer-layer deposition. The microhardness of the deposition form the bottom to the top roughly demonstrated a rising trend. In this paper, multilayer GH4169 Superalloy thin wall structure was prepared by additive manufacturing using electron beam melting. According to characteristics of electron beam rapid manufacturing technology, variation of microstructure and performance of the accumulation layer along the thickness direction was analyzed. The results showed that coarse columnar crystals in the formed GH4169 superalloy grew along the direction of the deposition, and the harmful Laves phase was found among the microstructure of the layer-layer deposition. The microhardness of the deposition form the bottom to the top roughly demonstrated a rising trend.

**W-P03**

**On the structure of K418 superalloy treated by laser cladding under a static transverse magnetic field**

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K418 superalloy is being used to create turbine blade, guide vane and other parts due to its excellent high temperature strength and corrosion resistance. Cracks often occur during service because of high temperature corrosion and erosion wear. Laser cladding is a wide use method to repair the cracked blades because of its high automation, small heat input, high performance of repair area etc. In order to future optimize structures of the laser cladding part a transverse static magnetic field has been applied during the proceeding. The experimental results show that microstructure within the treated part, in the case of no magnetic field, has a cellular growth feature, and a dendritic growth tendency appear when a 0.45T transverse magnetic field is imposed. For the latter case, the development of secondary arms can be observed. Such morphology change may be due to the damping effect of magnetic field on the melt flow. This is because a higher thermal gradient in the melting pool may be achieved when the melt flow has been damped.

**W-P04**

**Effect of magnetic field on microstructure of Al-12wt.%Si alloys fabricated by powder-blow additive manufacturing**

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Additive manufacturing has been regarded as a potential technology for fabricating the metallic components in this new century. This is because its layer-by-layer working strategy make directly fabricating the components with complex geometry possible, and the material is being additively deployed where it is needed, instead of
subtractively removed in the form of swarf and machining chips. Despite the great promise of additive manufacturing, there are still some inefficiencies (e.g., low build rates, limits in part dimensions), defects, microstructural issues, lack of process control. Aiming at controlling the solidification process during additive manufacturing, an external magnetic field has been introduced. Fabricating the Al-12wt.%Si alloys by powder-blow additive manufacturing with and without an 0.35T static transverse magnetic field has been carried. The results show that the structure of samples both with and without magnetic field consist of α-Al dendrites layers and the Al-Si eutectic dominate between the layers. Applying magnetic field shorten the distance between two α-Al layer and enhance the development of the dendrites’ high-order arms those embedded in the eutectic matrix. This may attribute to the damping effect of static magnetic field on the melt flow during laser melting and the following rapid solidifying.

W-P05
Microstructure and mechanical properties of electromagnetic stirring assisted laser forming repairing INCONEL 718 superalloy
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INCONEL 718 nickel based superalloy samples with V-grooves were experimentally repaired by laser forming repairing (LFR) assisted with electromagnetic stirring (EMS) under different magnetic field currents. The effects of the magnetic field currents on size of single pass repaired zone (RZ), microstructure and mechanical properties of multilayer RZ were experimental investigated. The width and deposition height of each trace measured by a laser manual measuring instrument were increased with the increase of the magnetic field current, and the penetration depth was found to be decreased inversely. The results show that the metallurgical bonding was conducted between the RZ and the substrate when the optimized process parameter was investigated. The microstructure in RZ is coarse columnar crystal when no electromagnetic stirring was used, which growing epitaxially along the deposition direction. With the increase of magnetic field current, the convection of liquid metals prompts the transformation from the coarse columnar crystal to fine equixed grains. The width and deposition height of the weld pool were measured by a laser manual measuring instrument, which found that width and deposition height ratio of weld pool changed from 3.26 when no electromagnetic stirring was used to 3.33, 4.14 and 5.14 when the applied magnetic field current was 20A, 40A, and 60A respectively. Electromagnetic stirring can improve the spreading of liquid metal in a certain extent. The tensile strengths of repaired components increased to 601, 764 and 889MPa from 406MPa for magnetic field currents of 20A, 40A, and 60A and no electromagnetic stirring was used.

W-P06
Morphology, Microstructure, and Hardness of Ti-6Al-4V Deposited by Wire and Arc Additive Manufacturing
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Metal additive manufacturing (MAM) allows for layer-by-layer fabrication of complex metallic parts with features typically unobtainable via conventional manufacturing. According to the energy beam we use, we can classify MAM as laser-based, electron beam-based, and arc-based. Compared with laser-based and electron-based
additive manufacturing which are adept in forming small-scale and precise complex components, arc-based AM, or wire and arc additive manufacturing (WAAM), developed for almost 20 years, has proved it’s significant potential in forming large scale components used in aerospace industry with cost saving and lead time reduction. In this paper, the experimental equipment we used includes welding source, TIG torch, wire feeder, and CNC. Then a straight wall is formed adopted single direction scan path, and the morphology, microstructure, and hardness of as-built and post-treatment Ti-6Al-4V are investigated and discussed. After being polished and etched to the cross-section along deposition height and width, the macrostructure can be observed with naked eyes, as-built sample is characterized by the outline of the horizontal deposited layers(layer bands) and grain boundaries remain from the large columnar prior b grains which grow as epitaxial type from substrate to the top. While the prior b grains boundaries will disappear when the solution temperature up to b transus and layer bands will fade when the solution or aging lasts sufficient time. The microstructure was investigated using optical and scanning electron microscopy(SEM, Tescan VEGA II LMH), it reveals basket-wave microstructure in as-built, and heat-treatment as well. However, the sort, size, shape, and distribution of phases are not all uniform for as-built, heat-treatment, and the heat treatment systems adopted. Acicular martensite with orthogonal arrangement in as-built sample shows a quite quick cooling after deposition, while this structure is not present in heat-treatment samples which drop their solution or aging temperature as furnace cooling(about 0.2K/s). For as-built sample, along b grain boundaries exists boundary $\alpha$ and $\alpha$ colony which hibits parallel $\alpha$ laminates, and other field mainly shows interlaced $\alpha$ laminates. By comparing the microstructure of different heat treatments(solution temperature, solution time, aging temperature, aging time), there exists some rules as follows, the width of $\alpha$ laminates grow when solution temperature or time increases, and second $\alpha$ phase will appear and combine as aging temperature raises, while there is no phenomenon showing what changes when aging time increases. In addition, the hardness of as-built and heat-treatment samples have tested by microhardness measurement, and the range of hardness of Ti-6Al-4V is broad.

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Comparison of PMN-PT transparent ceramics processed by three different sintering methods
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La-doped 0.75Pb(Mg1/3Nb2/3)O3-0.25PbTiO3 (PMN-PT) transparent ceramics were fabricated by pressureless sintering, uniaxial hot-pressing sintering and two-stage sintering technology, respectively. All the three ceramics are of pure perovskite phases. The characterization of dielectric property shows that the ceramics prepared by these three methods all exhibit relaxation characteristics. The values of the diffusivity coefficient were calculated according to the modified Curie-Weiss law. The $P-E$ hysteresis loops of these three ceramics are all inclined and slim. The values of remnant polarization ($P_r$) and coercive field ($E_c$) of the ceramics fabricated by these three different sintering methods have slight fluctuations. It was observed that the ceramic fabricated by two-stage sintering method showed best densification and clearest grain boundaries than two other ceramics. The transparent ceramic fabricated by two-stage sintering method exhibits the highest transparency around 70% at 900 nm which is very close to the theoretical transmittance 71%.

Heat Treatment Process for a New Hot Work Tool Steel
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In this paper, the effect of heat treatment process on microstructure and properties of a new hot work tool steel was studied. It's showed that there will be banding structure and segregation when the steel quenched at temperature lower than 1050 °C, with poor hardness and wear resistance. But after quenching at 1050 °C, the steel will exhibits uniform microstructure with higher hardness and good wear resistance. When the quenching temperature is raised to 1150 °C, the martensite will be coarsen for the steel and thus the hardness and wear resistance decrease. Cementite and alloy carbides are gradually precipitated in the steel during tempering after quenching at 1050 °C and its hardness and wear resistance increase. The size of alloy carbide increases and recovery and recrystallization occurs when the quenched steel tempered temperature is higher than 550 °C. In a word, for the new hot work tool steel, the optimum process of heat treatment, which is quenching in oil at 1050 °C and then twice tempering at 550 °C for 2 h, is recommended.

Multi-layer Functional Gradient Material of Stainless Steel Fabricated with Laser Melting Deposition
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In this study, the laser melting deposition technology was used to additively manufacture functionally graded stainless steel components. The influence of laser process parameters on the formability, microstructure and properties of the deposited component was studied. The formability, constituent phases, microstructure, chemical composition and hardness of stainless steel gradient components were investigated using OM, XRD, SEM, EDS and microhardness tester, respectively. Experimental results showed that stainless steel gradient components have been fabricated using optimized laser melting deposition technology. It also was seen that the microstructure was uniform and fine, and the as-deposited microstructure was mainly consisted of columnar dendrites directionally growing along the deposition direction. The combination between layer and layer was no pore and crack. Along the gradient direction, the microstructure, composition as well as microhardness of the prepared functional gradient material presented continuous change.

Study on Compatibility of Laser Forming Repaired Ti6Al4V Forgings with Intensive Titanium Alloy Powder
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The property compatibility between laser repairing zone and forging substrate were investigated experimentally in laser forming repaired Ti6Al4V forgings. The selected powder in the experiments were TC4(Ti6Al4V), TC4-20%TA15, TC4-30%TA15, TC4-40%TA15, TC4-50%TA15 and TA15(Ti-6.5Al-2Zr-1Mo-1V). The property compatibility included three aspects, namely, mechanical properties which mainly referred to tensile properties and microhardness, thermal properties consisted of specific heat capacity and coefficient of thermal expansion and chemical property which referred to corrosion resistance. Thereinto, tensile properties consisted of strength index of tensile strength and yield strength and plasticity index of elongation and the reduction of area were investigated at room temperature. Besides, the specific heat capacity was measured by means of sapphire method based on
ASTM E 1269 while the coefficient of thermal expansion was examined by Netzsch DIL402C dilatometer. These two thermodynamic parameters were measured from 30°C to 550°C. Moreover, the corrosion resistance was characterized by polarization curves tested in 3.5% NaCl solution. It was found that the microstructure of laser forming repaired was divided into three parts: Ti6Al4V forging substrate at the bottom, heat affected zone in the middle and repairing zone at the top while dense metallurgical bonding between laser repairing zone and forging substrate had been formed. The microhardness of specimens with different components along the direction of deposit were analyzed and then it was found that the microhardness increased gradually from the substrate to the repairing zone while the microhardness of repairing zone raised with the increase of Ti-6.5Al-2Zr-1Mo-1V contents. However, for the repairing zone the tensile strength and yield strength did not increase with the increase of Ti-6.5Al-2Zr-1Mo-1V contents which meant the laser repaired zone of Ti6Al4V had the maximum strength. The two typical components, one is Ti6Al4V and the other is Ti-6.5Al-2Zr-1Mo-1V, the yield strength and the tensile strength of the former were 1009.7MPa and 1097.8MPa respectively and the later were 955.64MPa and 1075.0MPa. For the repaired sample, the results showed that the strength of the whole region which included 50% repaired zone and 50% forging substrate decreased with the increase of Ti-6.5Al-2Zr-1Mo-1V contents. As well, the yield strength and the tensile strength of Ti6Al4V were 889.7MPa and 955.8MPa respectively and Ti-6.5Al-2Zr-1Mo-1V were 826.2MPa and 943.0MPa. In addition, it was found that the strength of laser repairing zone was higher than that of forging substrate. Obviously, for all the samples plasticity appeared opposite change with the change of Ti-6.5Al-2Zr-1Mo-1V contents. All the tensile results showed that Ti-6.5Al-2Zr-1Mo-1V had the best tensile properties compatibility between repaired zone and forging substrate among all the constituents. The tensile fracture also indicated that the strength of repaired zone was higher than that of forging substrate in that rupture occurred in the substrate. At the same time, the fractures of Ti-6.5Al-2Zr-1Mo-1V were almost ductile fractures while Ti6Al4V specimens were all mixed fractures which meant that the tensile plasticity of Ti-6.5Al-2Zr-1Mo-1V was superior to Ti6Al4V. Furthermore, the whole region of laser forming repaired specimens can be treated as a combination of strong + weak which made the strength lower and plasticity higher than forging substrate. The specific heat capacity and the coefficient of thermal expansion all followed general law that increased with the temperature increasing. Moreover, the specific heat capacity was mainly affected by the components which had an impact on atomic bonding force and thus Ti6Al4V had the best compatibility that the specific heat capacity of Ti6Al4V was the closest to that of forging substrate. However, an interesting result had been found that except for Ti6Al4V and forging substrate, every other component had a decline in the specific heat capacity with the increase of temperature when the temperature was higher than 475°C. Meanwhile, the experimental data was slightly lower than the results in the literature. For the coefficient of thermal expansion, the results revealed that it increased rapidly when the temperature was lower than 100°C but slowly at the higher temperature. Besides, the coefficient of thermal expansion of Ti6Al4V-50% Ti-6.5Al-2Zr-1Mo-1V was the closest to that of Ti6Al4V forging substrate. Similarly, with the exception of Ti6Al4V, every other component had a decline in the coefficient of thermal expansion with the increase of temperature when the temperature was higher than 475°C. The coefficient of thermal expansion mentioned here was average coefficient of linear expansion, namely, engineering α. The polarization curves indicated that corrosion resistance became better and better with the increase of Ti-6.5Al-2Zr-1Mo-1V contents which could be explained by free corrosion potential and corrosion current. It could be found that free corrosion potential went up gradually and corrosion current declined gradually with Ti-6.5Al-2Zr-1Mo-1V contents increasing. Furthermore, the corrosion resistance of repaired zone was superior than that of forging substrate. Hence, if considering compatibility only, Ti6Al4V had the closest corrosion resistance to that of Ti6Al4V forging substrate. In short, all aspects taken into account, Ti6Al4V-50% Ti-6.5Al-2Zr-1Mo-1V had the best compatibility with the substrate.

Study on laser multi-layer deposition of burn-resistant Ti40 alloy on Ti-6Al-4V substrate

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Titanium and titanium alloys are widely used in aviation, aerospace, ships, medicine and other industries due to its small density, high specific strength, thermal stability, corrosion resistance, good biocompatibility and other advantages. It is especially an indispensable key material in the design of advanced aero-engine. However, titanium and conventional titanium alloys have a fatal sensitive problem of sustained combustion in the harsh service environment of aero-engine with high performance. In the present study, a novel method of depositing burn-resistant Ti40 alloy on the conventional Ti-6Al-4V substrate by using laser multi-layer deposition technology was proposed. The influence of processing parameters and number of deposited layers on the geometric dimension, microstructure, metallurgical quality and hardness of the deposited layer and the heat affected zone were investigated. It was found that the deposited samples were with good metallurgical quality, and there was almost no defects, such as poor fusion, crack, porosity and so on. The height of deposited layer increase with the increase of laser power and the decrease of scanning speed, and the width of heat-affected zone increased with the increase of laser power and number of deposited layers, and the decrease of the scanning speed. The microstructure observation shows that deposited samples are composed by laser deposited zone, heat affected zone and substrate. The microstructure was consist of long needle like martensite cross distributed in the b-matrix in heat affected zone near the deposited zone while that was consist of Widmanstatten a colony near the substrate. In the deposited zone, it was composed by small bamboo-like columnar grains in the bottom and middle part while small equiaxed grains in the very top region, and the size of the equiaxed grains increased with increasing of the number of deposited layers. The micro-hardness test shows that the average micro-hardness increase with laser power and scanning speed at first and then decrease slightly.

The microstructure evolution of tungsten alloy by laser solid forming
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Varying percentages of tungsten-nickel alloy was used to melting by laser solid forming (LSF), and the relationship between process parameters and microstructure and properties was studied. A numerical modeling of solidification microstructure for LSF technology was set up by using CA method, the morphology and temperature distribution of molten pool was studied for the W-Ni alloy. By calculating the molten pool temperature and cooling rate under the condition of LSF W-Ni alloy, the CA model was used to simulation the solidification microstructure of different LSF process parameters. Results show that the gradient of temperature is an important factor to control solidification microstructure of LSF technology, and analysis the main factors affecting LSF molten pool temperature gradient. By the optimized process parameters, W90%-Ni alloy samples were fabricated by LSF technology, and the tensile strength can be reached 882MPa.

Laser-fabricated FeCoCrAlCuNiTi high-entropy alloy coating on NiTi plate
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Equimolar ratio of FeCoCrAlCuNiTi high-entropy alloy coating has been synthesized by laser surface alloying on NiTi substrate, aiming at improving the surface mechanical properties. The constituent phases, microstructure, chemical composition and hardness of the coating were investigated using XRD, SEM, EDS and microhardness
tester, respectively. Experimental results show that FeCoCrAlCuNiTi high-entropy alloy coating is observed to form single BCC solid solution instead of brittle intermetallic compounds. The solidified microstructure is mainly composed of dendritic-interdendritic structure. The microhardness of high-entropy alloy coating is more than 1300HV, which is ~3 times that of the NiTi substrate (420HV). Composition distribution curve demonstrates that a metallurgically bonding between the coating and the substrate is obtained. From the substrate to coating, the mixing entropy presents the gradual distribution from low entropy, medium entropy to high entropy.

Effects of process conditions on stress-deformation and forming precision of selective laser melted Ti6Al4V
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Selective Laser Melting (SLM) is one of laser additive manufacturing technologies, which can form complex three-dimensional metal parts by using the principle of “discrete+accumulation”. Besides, the forming precision is a critical factor which promotes SLM being widely used to aerospace manufacturing complex components, and stress-deformation is an important factor which affects the accuracy of forming. This paper aims at researching the dimensional accuracy caused by stress distribution and deformation. And stress distribution is measured by X-ray diffractometer, combining theoretical analysis and experimental measurement. Systematic studies are conducted by different process parameters (laser power, scanning speed, hatching spacing, powder layer thickness) and scanning strategy on the influence of stress deformation and dimensional precision. In addition, the heat treatment was carried out on the sample, comparing the results before and after heat treatment, the effect law of heat treatment on the stress distribution or forming precision can be gained. Furthermore, this work could lay the foundation of the stress and deformation optimization control and the improving of the forming precision.

Effect of print method based on SLM technology on the microstructure and mechanical property of 316L stainless steel
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The technology of selective laser melting (SLM) has become one of the most development potential technologies in the rapid prototyping and manufacturing field, and the important preparation method for the 3D print of metals. In addition to scanning interval, power and speed, the print method also affects the defects and comprehensive mechanical property of 3D print casting significantly. Therefore, the paper first printed the samples of 316 stainless steel using focus print and defocus print under the same process parameters with the scanning interval, power and speed of 0.05 mm, 450 W and 2000 mm/s, respectively. Then the samples were heat treated. Finally, the defects were observed by optical microscope (OM) and scanning electron microscope (SEM), and the tensile mechanical property at room temperature was tested. The results show that there only exist few cracks among the microstructure of the focus print sample; however there exist some holes among the microstructure of the defocus print sample. The focus print sample exhibits the better comprehensive mechanical property than the defocus print sample. The tensile strength, yield strength and elongation reach 645 MPa, 560 MPa and 45.0% for the focus print sample respectively, while they do 625 MPa, 545 MP and 38.0% for the defocus print sample, respectively. After heat treatment, the focus print sample also exhibits the less defects and better comprehensive tensile mechanical property.
Research on deformation rules of ceramic linear standard parts by extruded deposition modeling

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Now manufacturing ceramic parts with complex internal structures is unable to be solved. Therefore, the research and development of new ceramic parts forming technology has become an important research focus in the manufacturing technology. 3D printing technology appeared in the late 1980s. Three dimensional CAD data of parts could be directly used, and any complex shape parts were quickly manufactured. Thus, development of new products and manufacturing cycles were shorten in order to solve the problems existing in the traditional technology for ceramic manufacturing and provide a new technical way.

Ceramics appear in endless variety of compositions, technology and performances, so that ceramics are not specific like metal or plastic standard parts and have not general marks. In this paper, the concept of ceramic standard parts was put forward. And ceramic linear standard parts were prepared by extruded deposition modeling. The method is improved in FDM, and the print materials are replaced for ceramic mud with some plasticity. The special prepared mud is extruded by the external force, and through nozzle is continuously squeezed out. Then ceramic products are accumulated on working platforms by the computer control. Compared to FDM, in EDM the melting process of printing material is saved. Printing equipment structures are not only simplified, cost and energy consumption are reduced, and using machine becomes more safety and reliable.

Ceramic raw materials were mud section after vacuum pugging supplied by the Long-quan Jin Hong Ceramics Limited Company. The deformation rules of ceramic standards were studied, which can provide the specification for digital forming more fine ceramics in future and is easy to realize general standard grade like metal or plastic. The results show that laws of drying shrinkage and total shrinkage are that edge shrinkage increases gradually, and high shrinkage decreases little by little with addition of the side length. However, rules of sintering shrinkage is that with rise of the side length, the more high shrinkage reduces step and step, as the shape of a square, the side shrinkage appears an inflection point. For the same shape, the side shrinkage is compared to high shrinkage. High shrinkage of pentagon and hexagon is less than side shrinkage. The numbers of edge for polygonal line standard parts are same as the numbers of warp point, and the more number of polygon edges, the more anabatic warp degree becomes.