Preparation Technology and Heat Treatment Optimization of Tc4 Titanium Alloy

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Abstract: TC4 titanium alloy is widely used in important fields such as aerospace and has the advantages of low density, high specific strength, corrosion resistance, heat resistance, non-magnetism and good biocompatibility. However, due to its poor thermal conductivity, narrow forging temperature range, large deformation resistance, high temperature oxygen absorption and hydrogen absorption, there are many manufacturing and use problems in heat treatment process and preparation of large and complex structural parts. Based on the recent research progress of TC4 titanium alloy, the preparation technology and heat treatment optimization method of TC4 titanium alloy are described in this paper in order to be helpful to the manufacture and performance improvement of TC4 titanium alloy.

1. Introduction

Titanium and its alloys have high tensile strength and fatigue strength, low elastic modulus, low density and good corrosion resistance, and are widely used in aerospace and biomedical fields. TC4 titanium alloy (Ti-6Al-4V), as a medium strength $\alpha+\beta$ titanium alloy, has a wide temperature application range, good corrosion resistance and excellent mechanical properties. It is mainly used to manufacture aircraft fuselage, wing parts and engine blades, and is currently the most widely used titanium alloy [1].

2. Preparation Technology of Tc4 Titanium Alloy

2.1 Casting Molding

TC4 titanium alloy has good casting process performance and stable structure. Its service temperature is generally 300 ~ 400℃, and it has good strength and fracture toughness below 350℃. Casting titanium alloy is generally prepared by vacuum shell furnace and graphite casting method, which is mainly used to replace stainless steel in chemical industry. TC4 titanium alloy has the characteristics of high melting point, high activity in molten state and large deformation resistance, which makes the cast TC4 material loose in structure, more impurities and easy to produce defects such as shrinkage porosity, shrinkage cavity and porosity. These defects will directly affect the properties of the casting. At the same time, the cast grain structure is coarse and consists of lamellae with certain orientation relation, which will affect the strength, hardness, plasticity and toughness of the material. Titanium alloy ingots are often used to make cast titanium alloy and deformed titanium alloy.

2.2 Forging Technology

Forging is one of the main processing methods for titanium alloy structural parts. The ingot is first forged and bloomed by free forging, extrusion, flat forging, quick forging, precision forging and other methods to change the coarse as-cast structure into a deformed structure, thus preparing the structure for subsequent processing. The first fire forging of the ingot is open forging, and the rest is intermediate forging and finished forging. However, the forging temperature range of titanium alloy is relatively narrow, and the forging microstructure and properties are very sensitive

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to the forging thermodynamic parameters. In the forging process, with the increase of deformation rate, its deformation resistance increases significantly, showing strong strain rate sensitivity. Due to its poor thermal conductivity, it is easy to produce local overheating during forging, resulting in a large internal and external temperature difference, which intensifies the uneven distribution of internal and external deformation degree of the blank and easily leads to cracking during forging. Wang Bo et al. studied the microstructure and mechanical properties of TC4 titanium alloy bar in different forging processes. The results show that the strength of TC4 titanium alloy after forging by α+β forging, near β forging and β forging is equivalent. The three kinds of microstructure are equiaxed, mixed and lamellar respectively. The equiaxed and mixed microstructure have better plasticity and the mixed and lamellar microstructure have better impact toughness. The near β forging method can obtain the best comprehensive properties of TC4 titanium alloy bar [2]. Cai Guoshuai and others have studied the effect of cold rolling and annealing on the microstructure and properties of TC4 titanium alloy tube. Deformation and annealing have great influence on the cold rolling properties of TC4 titanium alloy tube. When the deformation is 36%, the cold rolled tube has better comprehensive properties. When the deformation reaches 46%, continuous crescent defects and cracks appear in the cold rolled tube. The optimal annealing temperature for cold rolling of pipes is 850℃, yield strength 810MPa, and elongation 22%[3].

2.3 Welding Technique

Tungsten inert gas shielded welding and metal inertia gas are the most commonly used methods for titanium alloy welding. The welding process is mature, but the large amount of heat input from electric arc makes it difficult to control the deformation generated during sheet welding. Electron beam welding and laser welding have great advantages and certain limitations in realizing full penetration welding with small deformation due to the characteristics of small heat input and high welding joint quality. Electron beam welding needs to be carried out in a vacuum chamber. When laser welding is used for titanium alloy connection, the assembly precision of workpieces is required to be high, the welding bridging property is poor, and defects such as undercut and the like are easy to occur in welds. Laser-arc hybrid welding is a process in which two heat sources, laser and arc, are combined by paraxial or coaxial and act on the same position of the workpiece. It combines the high speed, high efficiency, low heat input of laser welding and good bridging property of arc welding to realize metal material connection, and has become a research hotspot in the welding field in recent years. Ma Ran et al. conducted an arc compound welding test for 1mm thick TC4 titanium alloy sheet by optical fiber laser and tungsten inert gas shielded welding. The results showed that with the increase of arc current and the proportion of He gas in main shielding gas, the melting amount of the weld gradually increased, and the greater the energy input to the compound heat source, the more concentrated the energy, and the smaller the undercut depth of the weld. The greater the input heat, the worse the welding protection effect [4]. Yu Chen et al. used X-ray diffraction method to measure the distribution of residual stress on the surface of 100 mm TC4 titanium alloy electron beam welding head, and studied the effect of post-weld heat treatment on the residual stress of the joint [5]. From the perspective of controlling the level of welding residual stress, electron beam welding is a relatively ideal welding method.

2.4 Laser Deposition Technology

Increasing material manufacturing technology is a new rapid prototyping technology in recent 20 years. Its main features are no mould, short process, high flexibility and environmental friendliness, and the prepared materials are close to the final products. Therefore, it has great application prospect to prepare titanium alloy by using additive manufacturing technology. The Laser Melting Deposition Process (LMD) is a kind of manufacturing technology for adding materials. Metal powder is used as raw material, high-energy laser is used as energy source, and synchronously fed metal powder is melted layer by layer, rapidly solidified and deposited layer by layer according to a predetermined processing path. It has a series of advantages such as high material utilization rate, unrestricted shape and size of processed parts, and fast processing speed. The core component of

LMD is the laser cladding head. The powder feeder sends out the powder from the nozzle and focuses it on the axis below the cladding head. At the same time, the laser is focused near the powder focusing point through the focusing mirror to melt the synchronously sprayed powder. The cladding head moves according to the scanning track of each layer of pattern, and the three-dimensional entity is stacked layer by layer.

Laser deposition technology for TC4 titanium alloy is relatively mature and is an ideal method for preparing high-performance load dense parts. Meanwhile, TC4 titanium alloy can optimize the microstructure and properties by adjusting the composition, quantity and morphology of α and β phases, and can realize rapid near-net forming of high-performance complex dense parts. However, the forming process is a process of rapid heating and rapid cooling. The forming process will inevitably produce large residual stress and uneven alloy structure. The residual stress and Widmanstatten structure in the forming process cannot be eliminated simply by changing the laser scanning process parameters, and an appropriate heat treatment process is also required.

2.5 Surface Coating Technology

The surface coating technology of TC4 titanium alloy can improve the surface hardness and wear resistance of materials. Tao Qingshuang et al. prepared a zirconium alloy layer on the surface of TC4 titanium alloy by double glow ion infiltration technology, and oxidized the alloy layer to form a compact zirconia alloy layer by MP-CVD technology. The results show that zirconium and zirconium oxide alloy layers have higher microhardness and high corrosion resistance, zirconium oxide alloy layer has better effect, and the corrosion rate is reduced by two orders of magnitude compared with the matrix [6]. Guan Qingfeng et al. used HCPEB to Cr alloy TC4 titanium alloy surface. The hardness test and electrochemical results showed that the surface microhardness and corrosion resistance of the samples treated by HCPEB were significantly improved [7].

3. Heat Treatment Method and Performance Optimization of Tc4 Titanium Alloy

The properties of titanium alloy are related to its microstructure. There are four common microstructures: equiaxed structure, basket structure, bimodal structure and Widmanstatten structure. The primary α-phase and β-phase transformation structures of equiaxed tissues are uniformly distributed, with outstanding strength, plasticity and fatigue properties. Developed lamellae α are distributed in the original β grains in the net basket structure without obvious grain boundaries, and deformation is completed in the two-phase region. The bimodal structure is a β-transformed structure with a small amount of equiaxed primary α phase distributed on the matrix, taking into account strength, plasticity, toughness, fatigue and creep. Widmanstatten structure is β grain boundary integrity, there are developed lamellae α in grain boundary, grain boundary α is obvious, fracture toughness and creep properties are outstanding.

The main purpose of titanium alloy heat treatment is to reduce the internal stress generated in the preparation process, obtain the best plasticity, machinability, dimensional stability and tissue stability, improve strength, and optimize some special properties, such as fracture toughness, fatigue strength, high temperature creep and other properties. The notch strength, fracture toughness and fatigue resistance can also be improved by special heat treatment such as solid solution+aging, recrystallization annealing and β annealing.

In order to improve the microstructure and mechanical properties of TC4 titanium alloy, it is necessary to systematically study its related heat treatment process. He Bo et al. studied the effect of heat treatment on the microstructure and properties of laser deposited TC4. After solid solution at 970℃ for 2 hours and aging heat treatment, the microstructure of TC4 titanium alloy produced by laser deposition is a bi/tri-state structure consisting of equiaxed α, basket α and transformed β phase, with the best comprehensive properties [8]. Hu Jing et al. studied the forming process and heat treatment behavior of 3D printed TC4 titanium alloy, and found that the strength of 3D printed TC4 titanium alloy exceeded the requirements of national standard for annealed TC4 titanium alloy of castings and forgings, but the elongation after fracture was low. After solid solution and aging heat treatment, the strength of TC4 titanium alloy decreases slightly while the elongation after fracture increases obviously. The main reason is related to the transformation of the deposited Widmanstatten structure into the heat-treated basket structure [9]. Bao Xuechun and others have studied the effect of heat treatment process on the microstructure and mechanical properties of TC4 titanium alloy. The tensile strength of the two-state microstructure obtained by solid solution+air cooling+aging+air cooling and the equiaxed microstructure obtained by annealing+air cooling reach 986 MPa and 987 MPa respectively, and the plasticity is good. The tensile strength of Widmanstatten microstructure obtained by solid solution+air cooling+aging+air cooling is slightly lower than 949 MPa, but its plasticity is poor. Widmanstatten microstructure has the highest Vickers hardness value and equiaxed microstructure has the lowest hardness value, 358 HV0.1 and 331 HV0.1[1], respectively. Wei Xin et al. studied the effect of heat treatment system on the microstructure and properties of TC4 titanium alloy fan disk under the harsh conditions of comprehensive mechanical properties. The results show that: Compared with ordinary annealing, solution aging treatment has better microstructure uniformity and comprehensive mechanical properties. The optimal heat treatment system for TC4 titanium alloy fan disk forging is T β-(4060)℃/2h, WQ+700℃/2h, AC [10].

4. Conclusion

Laser deposition technology and surface coating technology are the most direct and effective ways to improve the hardness and wear resistance of TC4 titanium alloy. Reasonable heat treatment method can reduce stress, improve the microstructure of TC4 titanium alloy and optimize its service performance.

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