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Alpha and near alpha, alpha-beta, and beta and metastable-beta titanium alloys are processed to optimize strength and fatigue resistance using one of four basic methods.

Heat treatment of titanium alloys

Last month, I discussed the different types of titanium alloys. In this column, I will discuss the heat treatment of alpha and near alpha, alpha-beta, and beta and metastable-beta titanium alloys.

INTRODUCTION

With all the titanium alloys, there are four basic heat treatments used [1] [2] [3]:

›› Stress relief is used to reduce residual stress from welding, machining, and forming to improve dimensional stability and fatigue life without altering microstructure.

›› Annealing improves ductility, fracture toughness, and thermal stability by recovery and recrystallization and, for α–β alloys, by refining the α/β distribution.

›› Strengthening by solution heat treatment and aging, in α–β and β alloys, achieves high strength by creating supersaturated solid solutions that decompose into fine α precipitates during aging.

›› Beta annealing or duplex annealing is used to create lamellar microstructures that improve crack-growth resistance and high-temperature performance.

HEAT TREATMENT OF ALPHA, NEAR-ALPHA ALLOYS

Heat treatment is, for the most part, used for stress relief, annealing, and for optimizing creep resistance rather than increasing strength. Common practices include [1] [4] [5] [5]:

›› Stress-relieving: Typically, 595–705 °C for α/α–β alloys for 1–2 h followed by air cooling, used to remove fabrication-induced residual stresses without significant phase redistribution. [2] [5]

›› Mill or sub-beta transus annealing: Annealing below the β transus (in the α+β or single-α range) increases fracture toughness, ductility, and dimensional stability by promoting recovery and limited recrystallization of α [6] [7].

›› Duplex and recrystallization annealing uses higher-temperatures than sub-beta annealing by annealing in the upper α+β range. This is followed by controlled cooling to produce a duplex microstructure of primary equiaxed α in a transformed matrix, which is beneficial for creep and fatigue resistance [6] [7].

›› Solution treatment and aging is applicable to some near-α alloys containing Cu or moderate β stabilizers. In one example, Ti–2.5Cu can be solution treated at about 795–815°C, followed by water or air quenching. It is then aged in one or two steps to produce fine Ti_2Cu precipitates that increase strength. More heavily alloyed near-α materials (e.g., IMI-834) are solution treated just below the β transus and aged to approximately 600–625°C to optimize the balance of creep strength and toughness via controlled secondary α precipitation [3].

HEAT TREATMENT OF ALPHA–BETA ALLOYS

Titanium alloys of the α–β class are the most heat treatable of titanium alloys [1] [4].

›› Stress-relief is like α alloys, with temperatures in the range of 595–705°C for about 1–2 hours to reduce machining and forming stresses without major microstructural changes. For β-rich alloys, slightly higher stress-relief temperatures (700–800°C) with shorter times are common.

›› Sub-transus annealing is done by heating within the α+β range followed by air cooling to refine the balance between primary α_p and transformed lamellar α, improving toughness and fatigue resistance. Mill anneal temperatures for Ti–6Al–4V are typically just below the β transus to preserve a desired α_p fraction.

›› Duplex and recrystallization annealing is accomplished by heating to the upper α+β field to partially dissolve α_p and refine prior β grains. It is then cooled in a controlled manner to produce a duplex structure. Recrystallization anneals use higher temperatures and hold times to promote new grain formation where hot working has generated heavily deformed microstructures.

›› Beta annealing is performed by heating above the β transus to obtain a fully β microstructure. This is followed by relatively slow cooling (e.g., furnace or air) to room temperature. This yields coarse lamellar colonies and is often used to enhance fracture toughness and crack-growth resistance in thick sections, at the expense of yield strength and low-cycle fatigue performance.

›› Solution heat treatment and aging is accomplished by heating in the α+β field (or just above the transus in some cases). For example, Ti–6Al–4V is heated to 955–970°C to adjust the amount and composition of β. The part is then rapidly cooled by water or polymer quenching to retain a supersaturated mixture of β and possibly martensitic α^' or α'' [2] [6]. The alloy is then aged for several hours at 480–595°C to precipitate fine secondary α within β and refines the martensitic decomposition. This raises the strength significantly while maintaining fracture toughness [8].

HEAT TREATMENT OF BETA ALLOYS

Heat treatments for beta alloys are designed to use solution heat treatment and aging to produce fine precipitates of alpha or other precipitates.

Typical solution temperatures range from about 690–925°C, depending on composition. The times and temperatures are selected to ensure a fully β microstructure while avoiding excessive grain growth. For example, Ti–13V–11Cr–3Al is solution treated around 775–800°C, Ti–10V–2Fe–3Al around 760–780°C, and Ti–15V–3Cr–3Al–3Sn around 790–815°C [2] [6] [4] [3]. Quenching is usually by water quenching or polymer quenching, depending on section size or distortion constraints. However, if the alloy is very strongly β stabilized air cooling may be appropriate. The aim is to retain a supersaturated β phase with minimal continuous grain boundary α [5] [2].

Aging temperatures for β alloys are often between 425 and 595 °C for times from a few hours up to ~100 hours, producing controlled precipitation and growth of α. Lower temperatures and longer times favor very fine dispersions and peak strength, while higher temperatures promote coarser precipitates and better ductility [4] [3] [5] [7] [9].

CONCLUSION

In this article, the heat treatment of different titanium alloys was discussed.

For further details regarding the heat treatment of titanium alloys, and the commonly used processing times and temperatures for specific alloys, it is recommended that readers review AMS 2801D – Heat Treatment of Titanium Alloy Parts [10].

Should there be any comments or questions about this article, or suggestions for further articles, please contact the writer or editor.

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