

[54] PROCESSING FOR THE HIGH STRENGTH ALPHA-BETA TITANIUM ALLOYS

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abandoned.

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[58] Field of Search **75/175.5; 148/11.5, 12.7,
148/133, 32, 32.5**

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[57] ABSTRACT

A process for improving the toughness and property
uniformity of the high strength alpha-beta titanium al-
loys by a specific heat treatment schedule which in-
cludes a duplex solution heat treatment prior to aging.

2 Claims, 2 Drawing Figures

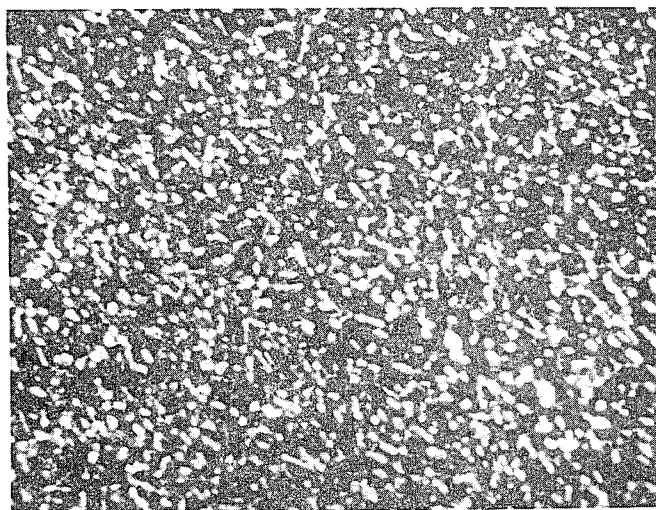


FIG. 1

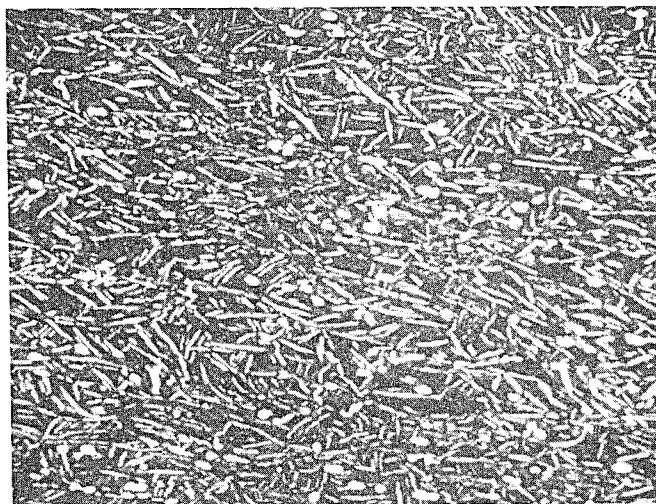


FIG. 2

PROCESSING FOR THE HIGH STRENGTH ALPHA-BETA TITANIUM ALLOYS

This is a continuation of application Ser. No. 200,723, filed Nov. 22, 1971, now abandoned.

BACKGROUND OF THE INVENTION

The present invention relates to the processing of the high strength alpha-beta titanium alloys to improve the level and uniformity of their mechanical properties.

The high strength alpha-beta titanium alloys, such as Ti 6-2-4-6 (6 percent aluminum, 2 percent tin, 4 percent zirconium, 6 percent molybdenum, balance titanium) and the Ti 6-6-2 alloy (6 percent aluminum, 6 percent vanadium, 2 percent tin, balance titanium), when processed by the conventional heat treatments exhibit a broad scatter in toughness, strength and fatigue resistance. The most common heat treatment for the Ti 6-2-4-6 alloy comprises: solutioning for about 1 hour at 1660°F.; air cooling; precipitation heat treatment at 1100°F. for 4-8 hours; and cooling in air.

The scatter in properties resultant from such heat treatment is directly related to microstructural differences within a given component and between components. In the standard processes, whether incorporating air cooling, oil or water quench after solutioning, the cooling rates between various sections of a given article cannot be well controlled due to differences in forging section size. Thus, for a given cooling technique from the solution temperature the thin sections tend to exhibit higher tensile and yield strengths and lower fracture toughness than thicker sections of the same forging. These variations in properties can be correlated with variations in alloy microstructure. In particular, there is the development of large amounts of very small secondary alpha plates in areas subject to rapid cooling and large, coarse alpha plates in the thicker sections which have cooled more slowly.

These property variations between different sections of a given article and between articles of different configuration and size are generally disadvantageous for the sensitive applications such as gas turbine engine hardware, where such alloys find their greatest utility.

SUMMARY OF THE INVENTION

It is a principal object of the present invention to improve the toughness and property uniformity of the high strength, age-hardenable, alpha-beta titanium alloys.

In furtherance of this objective, the present processing contemplates, prior to aging, a duplex solutioning heat treatment schedule comprising a first solution heat treatment to establish an optimum primary alpha phase content and beta phase grain size, followed, after cooling to room temperature, by a second solution heat treatment at a temperature low in the alpha-beta region to increase the size of the matrix or secondary alpha phase for improved toughness. Aging then adjusts the strength to the desired level.

In a preferred embodiment of the invention the Ti 6-2-4-6 alloy is processed by: a first solution heat treatment at about 1690°F. for 1-4 hours; cooling to room temperature; a second solution heat treatment at about 1525°F. for 1-24 hours; cooling; and subsequently aging at about 1100°F. for 2-8 hours.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a photomicrograph of the acceptable forging, before heat treatment, illustrating the equiaxed primary alpha in a transformed beta matrix (500x before reduction).

FIG. 2 is a photomicrograph of the acceptable forging, before heat treatment, showing short elongated primary alpha platelets with some degree of random orientation (500x before reduction).

DESCRIPTION OF THE PREFERRED EMBODIMENT

The high strength titanium alloys are desired for current lightweight, high performance turbine powerplants where a high specific modulus and creep strength are fundamental design criteria. Of intense interest are the age-hardenable, alpha-beta titanium alloys.

The Ti 6-6-2 alloy has been extensively investigated but, although high yield strengths are attainable with this alloy, it suffers somewhat from limited hardenability and low creep strength.

A recently developed high strength, age-hardenable, alpha-beta titanium alloy, which has its basis in the Ti 6-2-4-2 alloy, is the Ti 6-2-4-6 alloy earlier mentioned. The Ti 6-2-4-6 alloy has demonstrated high yield strengths and, in addition, has a greater hardening potential and higher creep strength than the Ti 6-6-2 alloy. Accordingly, it is the preferred alloy of current interest.

This alloy was purchased from the producer as eight inch round billet with an actual composition (K-2407) of 6.2 percent aluminum, 2.1 percent tin, 4.2 percent zirconium, 6.1 percent molybdenum, 0.06 percent iron, 0.12 percent oxygen, 0.008 percent nitrogen, 0.007 percent hydrogen, balance titanium. The alpha + beta to beta transus for this heat was determined to be 1735° ± 10°F. Several billet sections were cross-worked by multiple upset and redraw operations at 1625°F. to reduce the elongated alpha particle content and create a more homogeneous billet structure. Open die pancake forgings 1.75 inches thick and 18 inches in diameter were produced at a number of forging temperatures from 1625° to 1800°F. All pancakes were then cut into two or more sections and the effects of solution heat treatment at temperatures from 1525° to 1730°F. were investigated. Aging between 950° to 1100°F. usually completed each processing treatment.

The effects of cooling rate from forging temperature were studied. In addition, the quench rate from the solution treatment temperature was investigated in substantial detail by cooling various segments in different ways including air cool, oil quench and water quench. Mechanical property measurements and micrographs were obtained both near the surface and at the center of each segment, since these locations experienced different thermal histories.

It was readily apparent that, with the exception of a few data points, it was not possible to obtain the desired properties with the conventional processing treatments which had been employed. Those data points meeting the requirements were from pancakes which had been beta forged and water quenched from the forging press, a practice considered impractical for thicker sections. The basic problem in the conventional treatments arises because of the differences in cooling rate, in vari-

ous parts of an article, through the critical alpha plus beta range.

The trend for fracture toughness of these alloys to increase somewhat with decreasing percentages of primary alpha (equiaxed globular alpha) is shown when the amount of primary alpha is less than about 35 percent. This result is not totally unexpected since the ultimate condition of having no primary alpha is the tougher completely transformed beta structure which results from beta processing. However, the lack of a definite trend for all strength levels at higher percentages of primary alpha indicates that this variable alone is not sufficient to account for the effect of microstructure on the mechanical properties.

As mentioned above, the beta processed microstructures can be readily distinguished from the alpha-beta processed structures by their lack of primary alpha. In the alpha-beta processed material the microstructures which yield the highest fracture toughness at yield strength levels between 170 and 180 k.s.i. may be defined as containing about 10 percent globular alpha (primary alpha) with a matrix of relatively coarse acicular alpha (secondary alpha) and aged beta. An acceptable level of tensile ductility (20%RA) is also obtained with this microstructure.

The basic microstructure is, of course, usually tailored to some extent depending upon the particular application in mind and, hence, the particular goal properties desired.

For a gas turbine engine compressor disk, for example, in the strength/toughness trade off as part of the alloy property optimization process, more coarse alpha is built into the alloy providing increased toughness somewhat at the expense of strength. For a compressor blade application, however, the strength/toughness trade off would typically be reversed, providing increased strength even if the achievement thereof were provided somewhat at the expense of toughness.

The fracture toughness and resultant critical crack size for rapid fracture of a given specimen is a function of the yield strength. The critical crack size for unstable fracture in plane strain is known to be proportional to $(K_{IC}/\sigma_y)^2$ where K_{IC} is the critical plane strain stress intensity factor and σ_y is the yield strength. It is possible, however, to modify microstructural features to increase fracture toughness at a given strength level by creating random preferred crack growth paths in the structure. These preferred crack growth paths are along alpha plate interfaces and control of the size and orientation of alpha plates is necessary to achieve fracture toughness at high strength levels in alpha-beta titanium alloys. At a typical yield strength goal of 170 k.s.i. the K_{IC} goal was 35 k.s.i. $\sqrt{\text{in.}}$.

The K_{IC} goal was achieved by a first solution heat treatment high in the alpha/beta range to adjust the quantity and morphology of the alpha phase, cooling to room temperature either by quench or air cooling, followed by a second solution heat treatment low in the alpha/beta range providing alpha growth and an increase in fracture toughness. Subsequent conventional aging is then performed.

The basic forging microstructure comprises substantially equiaxed primary alpha in a transformed beta matrix resultant from forging at a temperature up to 1700°F., typically 1625°-1650°F., in the case of the Ti 6-2-4-6 alloy. The forging goal microstructure, before heat treatment, is shown in FIGS. 1 and 2. FIG. 2 shows

alpha platelets of some, but acceptable, elongation within the basic equiaxed alpha definition herein. Forgings with coarser elongated alpha platelets which are less fragmented or exhibit less random orientation are considered rejectable, as is a lack of primary alpha.

The first solution heat treatment is conducted generally at temperatures up to about 1700°F., typically at about 1690°F. for 1-2 hours, the holding time being dependent on section size but being sufficient in any event to provide relatively uniform heating. The first solution temperature, however, must be high enough to control the size of the beta phase since the beta subsequently controls the size of the alpha platelets. At solution temperatures too high above the beta transus subsequent ductility is poor. This first solutioning is therefore conducted basically below the beta transus temperature, typically about 10°-50°F. therebelow, but within about 100°F. thereof.

The second solution heat treatment, after cooling to ambient, is conducted within the general range of the alpha transus to about 200°F. thereabove, in the range, therefore, of about 1400°-1600°F., preferably 1500°-1575°F. This second solution heat treatment is utilized to increase the size of the alpha plates for improved toughness. Times from 1-24 hours or longer are used, depending upon the specific solution temperature and the degree of growth desired.

Aging is conventional, typically in the 950°-1100°F. range for 2-8 hours or longer.

Several thermomechanical approaches may, in fact, theoretically be utilized to build both strength and toughness into the titanium alloys. The basic problems and factors leading to the preference of one or the other relate primarily to differences or conditions in terms of cooling rate through the critical alpha/beta range.

As previously described, the object microstructure in the fully heated treated alloy comprises about 10 percent primary alpha in a matrix of relatively coarse secondary (acicular) alpha and aged beta. To generate such a microstructure, the first step in each approach is a solution heat treatment high in the two phase alpha/beta region to develop a small amount, permissibly 5-30 percent, but preferably about 10 percent primary alpha. If forging, rolling or extrusion in the preparation of the forging has been performed at a sufficiently high temperature, then it is, in fact, a solution heat treatment. The low temperature forgings, with forging conducted at 1625°F. for example, are characterized by an overabundance of primary alpha.

For thin sections, air cooling following the first solution heat treatment may be rapid enough to provide the desired microstructure, particularly substantial retained beta. Usually, however, a rapid cooling or quench through the alpha/beta range is preferred, and is required for the proper treatment of articles of varying thickness.

The acicular alpha which forms at the lower temperatures in the alpha/beta range is developed in the microstructure by a second solution heat treatment low in the alpha/beta range.

In a copending application entitled "Processing for the High Strength Alpha-Beta Titanium Alloys," Ser. No. 187,037 filed Oct. 6, 1971 now U.S. Pat. No. 3,748,194, the component, from the first solution treatment, is preferably quenched to and held at a temperature low in the alpha/beta range and the desired micro-

structure is developed by an isothermal transformation mechanism in a very short period of time, typically 15 minutes.

In the present process, the component is rapidly cooled from the first solution treatment temperature to room temperature and is then reheated to a temperature low in the alpha/beta range for solutioning and the development of the desired microstructure by a particle growth mechanism involving long term processing, typically 1-24 hours.

The effect of the second solution heat treatment temperature (at a constant 4 hours) on the amount and morphology of the acicular alpha was investigated. It was observed that fewer but coarser acicular alpha particles are produced at 1600°F. than at 1500°F. Thus, at 1500°F. the growth of individual acicular alpha particles is slower than at 1600°F. while at 1600°F. the quantity of alpha particles is reduced because of alpha and beta phase equilibrium conditions which cause some alpha phase particles to transform to beta phase.

The effect of time at a constant second solution temperature was also investigated. After one hour at 1550°F., an abundance of very fine acicular alpha was observed between the globules of primary alpha. In 4 hours the number of alpha needles had diminished and those that remained had coarsened significantly without any noticeable change in the primary alpha. At 16 hours at this temperature, the secondary alpha had grown so large as to be practically indistinguishable from the primary alpha. The maximum length developed by the acicular alpha had been limited by the amount of primary alpha already present in the microstructure.

Aging to the desired strength comprised the final heat treatment in all cases.

In summary, a desirable microstructure providing a good combination of strength and toughness to the alpha/beta alloys of the type represented by Ti 6-2-4-6 comprises about 5-30 percent equiaxed primary alpha in a matrix of relatively long, coarse secondary alpha and retained beta platelets.

This desirable microstructure has been provided by a first solution heat treatment near but below the beta transus, typically 10°-50°F. therebelow, but within 100°F. thereof, furnishing the optimum primary alpha phase content as well as the desirable beta grain size. Following rapid cooling, preferably quenching, to room temperature from the first solution heat treatment, the

alloy is reheated to a temperature in the alpha/beta range near the alpha transus, typically within 200°F. thereof, to increase the size of the secondary alpha for toughness, the process proceeding by a particle growth mechanism. Aging then adjusts the strength to the desired level.

The invention in its broader aspects is not limited to the specific details described but departures may be made therefrom within the scope of the accompanying claims without departing from the principles of the invention and without sacrificing its chief advantages.

We claim:

1. The method of providing improved toughness to alloy forgings of a nominal composition consisting essentially of, by weight, 6 percent aluminum, 2 percent tin, 4 percent zirconium, 6 percent molybdenum, balance titanium, the forgings including portions of varying thickness which comprises:

solution heat treating the forgings at a temperature of 1600°-1700°F. for a minimum of about 1 hour, developing in the alloy about 5-30 volume percent of a globular alpha phase;

quenching the forging at a rate in excess of air cooling to ambient temperature;

reheating the forging to a temperature of about 1400°-1600°F. for 1-24 hours, providing growth of an acicular alpha phase therein for improved toughness;

and, after cooling, aging the alloy at a temperature of about 950°-1100°F. for at least about 2-8 hours for improved strength.

2. The method of improving the toughness of alloy forgings of a nominal composition consisting essentially of, by weight, 6 percent aluminum, 2 percent tin, 4 percent zirconium, 6 percent molybdenum, balance titanium, the forgings including portions of varying thickness which comprises:

solution heat treating the forgings at about 1690°F. for 1-4 hours;

quenching the forging at a rate in excess of air cooling to room temperature;

reheating the forging to a temperature of about 1525°F. for 1-24 hours, the time being selected to provide the desired degree of toughness;

and, after cooling, the forging, aging at a temperature of about 1100°F. for about 2-8 hours.

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