INFLUENCE OF THE HEAT TREATMENT AND NOTCH ORIENTATION ON THE FRACTURE TOUGHNESS OF A Ti - 6 Al - 4V PLATE

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The influence of heat treatment and specimen orientation on both microstructure and mechanical properties of a 17 mm thick Ti-6Al-4V have been analised. Air cooled from the beta field samples exhibited a marked increase in toughness and near identical values were measured in both orientations. However, when this beta field treatment is followed by water quenching a certain decrease in toughness was detected. Heat treatments below the transus followed by slow cooling produced a good combination of ductility and toughness. Alpha-beta heat treatments followed by water quenching did not induce the increase of any property compared with the as-received material.

INTRODUCTION

To achieve the optimum combination of mechanical properties in metallic materials is not an easy work. Within a given class of materials there is generally an inverse relationship between strength and toughness (1). This task is even more complicated in titanium alloys. According to the first published papers on this subject beta field heat treatments produced the highest fracture toughness but the important drawback of a poor ductility (2-5). Although, more recently the existence of a strong influence of the size, morphology and nature of the needles and plates obtained by means of these beta field treatments on fracture toughness has been claimed (6-9) the decrease in ductility is universally accepted. It was suggested that recrystallisation annealing performed below the beta transus would lead to a very good combination of ductility and toughness (10). This possibility was explored in a previous work carried out on 20 mm diameter bars. A very good combination of ductility and toughness was achieved even if the values of fracture toughness were lower than those measured in samples which were air cooled from the beta field.

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Moreover, at least inside the studied range of times and temperatures, fracture toughness was improved by an increase in any of these parameters. Another treatment that has been proposed to obtain an optimum balance of fracture toughness, ductility, creep and stress rupture properties consisted in rapid quenching from a temperature high in the alpha-beta field followed by ageing at temperatures between 425 and 650° C, or even higher temperatures when it is looked for better properties of notch strength, toughness and creep strength at strength levels similar to those obtained by regular annealing (12).

The aim of this paper is to investigate the effect of heat treatment and notch orientation on the fracture toughness of a 17 mm thick Ti - 6 Al - 4 V plate.

EXPERIMENTAL PROCEDURE

The material chosen for the present study was a 17 mm thick of Ti-6Al-4V alloy, whose chemical composition is given in Table 1. In the as- received condition this plate was mill annealed (MA), that is a short maintenance at 720° C, followed by air cooling as the final step of their thermomechanical process.

TABLE 1 - Chemical Composition of the Plate

Al	V	Fe	C	O	N	H	Ti
6.51	4.08	0.16	0.01	0.19	0.005	0.0016	Bal.

Various samples obtained from this plate were heat treated in a small laboratory furnace under argon protection. Table 2 summarizes this treatments.

TABLE 2 - Heat Treatments of the Various Samples

BA	1030° C	1/2 h	Air cooled aged at 730° C 2h. air cooled
WQ	1030° C	1/2 h	Water quenched aged at 730° C 2h air cooled
940/1	Ann. 940° C	1 h	Furnace cooled to 700° C and air cooled
940/4	Ann. 940° C	4 h	Furnace cooled to 700° C and air cooled
940/8	Ann. 940° C	8 h	Furnace cooled to 700° C and air cooled
STA 1	Ann. 940° C	1 h	Water quenched aged at 730° C 1h. air cooled
STA 2	Ann. 940° C	1 h	Water quenched aged at 730° C 2h air cooled
STA 4	Ann. 940° C	1 h	Water quenched aged at 730° C 4h air cooled

Tensile properties were determined using standard specimens machined from these heat treated coupons in the longitudinal or transverse directions. Tests were performed at room temperature in accordance to ASTM E8M standard requirements. Fracture toughness characterization consisted of room temperature CTOD tests, using three point bend specimens, obtained from these treated coupons and notched in the L-T or T-L orientations. These tests were carried out, following BS 5762. The influence of the different heat treatments on the microstructure of the material was analysed by means of light microscopy.

RESULTS AND DISCUSSION

The results of the tensile and fracture toughness of the material in the various heat treating conditions and specimens orientations are listed in Table 3. It is observed in this Table 3 that in the as-received condition L-T specimens showed a higher fracture toughness than T-L ones. This behaviour agrees with that observed in most metallic materials but contradicts the trend observed in other titanium alloys where higher toughness is detected in the T-L orientation (13, 14). This dissimilarity has been attributed to differences in the texture of the material induced by the rolling process. Ti Code 12 studied in the previous paper possesed a basal transverse texture developed by unidirectional rolling (13) but in the present material a basal type texture was observed.

Heat treatments which were carried out at temperature above the beta transus produced a marked loss in ductility that is reduced to about half the original values. The more pronounced difference between air cooled and water quenched specimens must be found in the fracture toughness values. Air cooled samples(BA) exhibited a marked increase and a greater isotropy in toughness, doubling the values measured in the mill annealed condition. However, water quenching did not produce any improvement in toughness and even a certain decrease can be detected. A similar behaviour was observed in 20 mm diameter bars studied in a previous paper (11) Metallographic examination helps to explain the reasons for this different behaviour. BA samples exhibited relatively fine needles of alplha phase which have a basket-weave appearance. When the alloy is water quenched there is no sign of alpha phase and very fine, straight needles of alpha prime martensite were formed (15).

Samples that were heat treated at temperatures below the beta transus and slowly cooled in the furnace exhibit a very good combination of ductility and toughness and a greater homogeneity of properties. The only exception were specimens treated for a very short period of 1 hour that did not show any remarkable variation compared to the as-received material that was attributed to an incomplete recrystallisation. Longer periods of maintenance induced a rise in the values of toughness although they were always lower than those recorded in BA samples. Metallographic examination allowed to detect the changes in the microstructure induced by heat treatment.

TABLE 3 - Effect of the Heat Treatment and Specimen Orientation on the Mechanical Properties

Ref.	Orient.	Y.S. (Mpa)	UTS (Mpa)	Elong. (%)	CTOD (mm)
MA	L-T	967	1043	17	0.032
MA	T-L	1010	1085	16	0.026
BA	L-T	930	1018	8.3	0.070
BA	T-L	908	1023	8.3	0.070
WQ	L-T	965	1034	7.8	0.026
WQ	T-L	971	1047	7.6	0.026
940/1	L-T	895	979	15.4	0.033
940/1	T-L	892	988	15.8	0.029
940/4	L-T	894	1022	15.	0.039
940/4	T-L	898	1022	15.7	0.038
940/8	L-T	896	1017	15.1	0.045
940/8	T-L	895	1025	15.8	0.048
STA1	L-T	950	1069	14.3	0.027
STA1	T-L	966	1078	15.1	0.031
STA2	L-T	976	1087	14.7	0.028
STA2	T-L	987	1094	14.8	0.027
STA4	L-T	982	1093	14.5	0.024
STA4	T-L	1022	1099	13.0	0.027

Longer periods of maintenance produced more equiaxic grains of alpha phase and increase the mean free path of the beta phase sited at the alpha grain boundaries. According to the few available data a direct relationship between the beta phase mean free path and the fracture toughness values very similar to that obtained in 20 mm diameter bars of the same alloy (11) can be proposed although indepth research is recommended to obtain a definitive conclusion.

Alpha-beta field heat treatement for various times which were followed by water quenching did not produce any noticeable increase in strength and even a certain decrease in ductility and toughness, which seems to be slightly more marked as the heat treating time rises, can be observed. Probably, the selected ageing temperature was excessively high and the use of lower temperatures must be explored before to dismiss these treatments. Nevertheless the brittle character of alpha prime martensite cannot be forgotten.

CONCLUSIONS

1.- In the as-received (MA) condition L-T specimens exhibited a slightly higher fracture toughness. This behaviour has been associated with the basal texture of the material.

2.- Samples which were heat treated above the beta transus possessed poor ductility. When this treatment was followed by air cooling the maximum fracture toughness in both L-T and T-L orientations was achieved. However, when the alloy is water quenched even a certain decrease in toughness compared to the original condition ones was detected.

3.- Alpha - beta field treatments which were followed by slow cooling produced the optimum combination of ductility and toughness and a greater isotropy. At least inside the studied range, the later property seems to rise as the maintenance time increases although the recorded values are lower than those obtained in the BA condition.

4.- Specimens which were treated in the alpha - beta field but water quenched and aged did not show any improvement in the properties and even a slight decrease in toughness attributed to the presence of brittle alpha prime martensite was observed. Nevertheless, indepth research is needed before a definitive conclusion could be reached.

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