MICROSTRUCTURAL STUDY OF THE NEW INDUSTRIAL ALLOY (TI6211) (TI 6W/O AL -2W/O NB -1 W/OTA - 1W/O, MO), USING OPTICAL MICROSCOPY (OM) AND SCANNING ELECTRON MICROSCOPY (SEM)

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1.0 ABSTRACT

Ti 6211 developed for marine and other engineering applications in harsh environment was characterized microstruturally using optical microscopy and the scanning electron microscopy.

Acicular, plate-like, lath and packet martensitic microstructures and basketweave or widmanstatten microstructures were observed on the optical micrographs. While martensitic microstructures were observed on samples heat treated at 800°c or 900°C or 1070°C, the basket weave or widmanstatten and alpha colony were observed on samples heat treated at 400°C, 500°C and 600°C.

On the scanning electron images, films of supersaturated retained beta phase were observed along alpha plates while grain boundary alpha located along the grain boundaries and at the tri-junctions of the grains. These findings agreed with the literature on the microstructures observed in titanium alloys. As microstructures affect the material behaviour in engineering applications, the findings in this study will influence positively material design involving titanium.

Keywords:

Titanium, basket weave microstructure, alpha colony orthorhombic, martensite.

2.0 INTRODUCTION

The new industrial alloy Ti 6211 (chemical composition (w/o) = Al = 5.8, Nb = 2.06, Ta = 0.96, Mo = 0.06, Fe = 0.04, C = 0.03 Ti (balance), was developed for possible marine applications requiring thick sections.

The microstructure of titanium alloys especially the near alpha (α) or $\alpha + \beta$ Titanium alloys has a great influence on various mechanical properties such as strength, ductility, fracture toughness and low cycle fatigue in harsh environments (Borradeile and Jeal, 1980). Beta (β) titanium alloys have been widely used for their good high strength/high toughness potential but they exhibit low aged tensile ductility especially in the transverse direction of rolling (James and Moon, 1970). Hence beta -Ti alloys have restricted use especially in forgings or sheet rolling and that is why heat treatment of Ti alloys is necessary.

Plate-like morphology of alpha often described as widmanstatten structure had been reported in titanium alloys resulting from nucleation and growth after cooling from the beta phase

(Murakami, Yotaro, 1980). The formation of the colony and basketweave microstructures had been reported in titanium alloys after cooling from the beta or $\alpha+\beta$ fields (Liu and Margolin, 1953). In addition to the alpha morphologies which result from nucleation and growth or from tempering of martensite, hot working or thermo-mechanical processing at temperatures in the $\alpha+\beta$ phase field had an important effect on alpha-phase morphology.

In quenched Ti alloys; the martensitic structure typically exhibited a plate-like morphology and in some alpha alloys, lath or packet martensite could be formed (Williams et al, 1980). The alpha prime (hexagonal) martensite in the quenched Ti alloys had been reported to exhibit massive or packet or lath martensite (Williams et al, 1970) and acicular morphologies (Macmillan et al, 1967).

The massive martensite was found to consist of colonies which were resolvable optically (Liu and Margolin, 1953). From x-ray analysis and electron microprobe study of Ti 6211 it was found that the prevalent phases in this alloy at 500°C and 600°C were α_0 (hcp) and α'' (orthorhombic martensite) and at 700°C, 800°C and 900°C were α_0(hcp), ' (hcp martensite) and β retained (BCC) (Obikwelu (1982), (2003).

The objective of the present study was to characterize the new industrial titanium alloy Ti 6211 microstructurally.

3.0 MATERIALS AND METHODS:

3.1 Materials:

The sample was obtained as a plate from the Office of Naval Research in Washington DC in the United State of America. This as received plate was cut into (3x2x2)cm^3 for subsequent slight hot deformation, heat treatment, optical microscopy and the scanning electron microscopy.

3.2 Methods:

The (3 x 2 x 2)cm^3 cubes were polished in 120 grade adhesives to remove blade marks and flatten the surfaces. More polishing was done through 600 grit before the samples were hot-worked at about 1090°C and air-cooled. The hot-worked samples were profusely polished to remove any alpha case and oxidized layer.
The clean samples of final dimension (3 x 1 x 1)cm^3 were subsequently polished to 600 grit and then heat treated in a specially designed two-zone co-axial furnace assembly circulated by argon gas at 400°C, 500°C, 600°C, 700 °C, 800 °C, 900 °C, 1070 °C respectively (Obikwelu, 1982).

Optical Microscopy

The heat-treated samples were ground flat and any trace of oxide or coloration removed with the water cooled Bulher Belt surfaces. Rough polishing was done on 240, 320, 400 and 600 emery papers adequately cooled to avoid deformation. Final polishing was done on the polishing wheel with micro-cloth using 0.5micron alumina. The samples were etched for 40 seconds in 95cc H_2O, 3.5cc HNO_3, and 1.5cc HF (Kroll's etchant) and washed in water and then methanol and dried.

An Olympus table microscope was used to have a quick glance on the samples but photomicrographs were taken with a Heerbrugg Wild Microscope Model M20 with attached 35mm camera.

Scanning Electron Microscopy:
The samples prepared for the optical microscopy were also used for scanning electron microscopy to produce scanning electron images of the microstructure of the new alloy Ti 6211.

4.0 RESULTS AND DISCUSSION:

4.1 Results:

Below are the optical micrographs and scanning electron images of the microstructures detected in Ti 6211.

Fig. 1: Optical Micrograph of the as-received Ti6211 showing fine alpha + beta colony microstructure. Etchant was Kroll's solution, Mag: 200X

Fig. 2: Optical Micrograph of Ti6211 annealed for 30minutes at 1070°c and 900°c and quenched in water at room temperature, sharing acicular and plate-like morphologies of titanium martensite. Etchant was Kroll's solution, Mag: 200X.

Fig. 3: Optical Micrograph of Ti6211, Etchant = Kroll's solution. Mag = 150X

A: Basket weave microstructure for sample Annealed at 400°c and quenched in water at room temperature.

B: Alpha colony microstructure for sample annealed at 500°c and quenched in water at room temperature.

C: Alpha colony microstructure for sample annealed, at 600°c and quenched in water at room temperature.

Fig.4: scanning electron image of Ti 6211 annealed for 30 minutes at 900°c and quenched sin water at room temperature Etchant was Kroll's solution. Mag: 570X

Fig.5: Scanning electron image of Ti6211 showing the alpha blocks in the tri-junction. Etchant was Kroll's solution. Mag: 500X

4.2 Discussion:

The optical micrographs of this new industrial Ti alloy showed the following microstructures: Alpha colony, basketweave or the widmanstatten, acicular and plate-like.

(Liu and Margolin, 1980) had shown that with an increasing amount of beta stabilizing solutes in the beta phase, the independent nucleation of separate plates was enhanced and the colony microstructure was replaced by the basketweave or the widmanstatten microstructure. This was confirmed by the occurrence of typical alpha colony microstructure at 600°c and the basketweave microstructure at 500°c for Ti 6211, shown in fig. 3.

These microstructures further confirmed that the beta stabilizers in the equilibrium beta increased as the annealing temperatures were lowered (Obikwelu, 2004).

The occurrence of acicular martensitic microstructure in Ti alloys (Macmillan 1967) and that of massive or packet or lath martensite microstructure in Ti alloys (Williams et al. 1970) was confirmed in the present study as shown in figures 2, 4 and 5.

Figures 4 and 5 show the scanning electron images of the Ti 6211 solution- treated in the beta phase field for 30 minutes at 900°c and quenched in water. The martensitic plates occurred as alpha prime (α') plates, the retained beta phase as inter-plate films and alpha (α) appeared in colonies.

Figure 4 also shows the heterogeneously nucleated grain boundary alpha which wiped off the prior beta grain boundary. This alpha-plate nucleated and grew along the grain boundary to form a continuous grain boundary alpha.

It will be noted that at high annealing temperatures such as 900°c or 800°c, a heterogeneous nucleation equilibrium alpha phase occurred at the prior beta grain boundaries. As this grain boundary alpha grew there was a depletion of Al (and then a super-saturation of beta stabilizers) adjacent to the grain boundaries. The grain interior did not suffer such an Al depletion. Thus simultaneously or concurrently equilibrium alpha colonies formed at the grain interior. The remaining matrix, after isothermal heat treatment, consisted of beta-phase. In the retained beta region, the volume adjacent to a grain boundary was the most saturated beta because of the higher diffusion rate of the solute, near the boundary. Upon quenching the beta-phase transformed martensitically giving rise to a "packet" type martensitic structure. The retained beta near the grain boundaries, however was supersaturated with beta stabilizers to such a degree that upon cooling or quenching to room temperature, it was retained. X-ray diffraction data (Obikwelu, 1982) confirmed the existence of the beta phase in titanium alloys quenched from 800°c and 900°c.

5.0 CONCLUSION:

Thus the scanning electron and optical microscopic studies of the new Ti alloy (Ti 6211) had confirmed the existence of acicular, plate-like or lath or packet martensites, equilibrium alpha colonies and enriched retained beta phase between the grain boundary alpha and the martensitic packets according to the literature.

As these microstructures influence immensely mechanical properties of this class of alloys material design involving titanium alloy systems is further enhanced by the findings of this study.

6.0 REFERENCES

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