Research Article

Effects of Heat Treatment on the Mechanical Properties of Al-4% Ti Alloy

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Received 19 August 2013; Revised 29 October 2013; Accepted 30 October 2013

Academic Editor: Koppoju Suresh

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This paper examines the effects of heat treatment processes on the mechanical properties of as-cast Al-4% Ti alloy for structural applications. Heat treatment processes, namely, annealing, normalizing, quenching, and tempering, are carried out on the alloy samples. The mechanical tests of the heat treated samples are carried out and the results obtained are related to their optical microscopy morphologies. The results show that the heat treatment processes have no significant effect on the tensile strength of the as-cast Al-4% Ti alloy but produce significant effect on the rigidity and strain characteristic of the alloy. With respect to the strain characteristics, significant improvement in the ductility of the samples is recorded in the tempered sample. Thus, for application requiring strength and ductility such as in aerospace industries, this tempered heat treated alloy could be used. In addition, the quenched sample shows significant improvement in hardness.

1. Introduction

Aluminium like all pure metals has low strength and cannot be readily used in applications where resistance to deformation and fracture is essential. Therefore, other elements are added to aluminium primarily to improve strength. The low density with high strength has made aluminium alloys attractive in applications where specific strength (strength-to-weight ratio) is a major design consideration. For structural use, the strongest alloy which meets minimum requirements for other properties such as corrosion resistance, ductility, and toughness is usually selected if it is cost effective. Hence, composition is the first consideration for strength [1]. Structural application of aluminium alloy at high or moderate temperature requires a fine, homogeneous, and stable distribution of crystal hardening up to the temperature of use. High melting point intermetallics phases are good candidate for that. Al_3Ti is very attractive among all intermetallics, because of its high melting point (1350°C) and relatively low

density (3.3g/cm^3) [2]. Recently, aluminium based alloys, especially with titanium, are becoming more useful for high temperature applications due to their excellent properties [3]. Previous researchers have looked mainly at the effect of titanium as a grain refiner in aluminium alloy as grain refinement plays an important role in determining the ultimate properties of aluminium alloy products. It improves tensile intensities and plasticity, increases feeding complex castings, and reduces the tendency of hot tearing and porosity [4]. In reality grain refinement of aluminium by titanium is due to the occurrence of a peritectic reaction at the aluminium-rich end of the aluminium-titanium phase diagram [5, 6]. A combination of titanium addition to aluminum alloy and other processing is thought as possible means of further improving the mechanical properties of this alloy especially for high temperature usage.

Thus, in this study, the effect of heat treatment is employed as a means of improving the mechanical properties of aluminium-4% titanium alloy.

TABLE 1: Chemical composition of as-cast Al-4% Ti alloy.

Element	Fe	Si	Mn	Cu	Zn	Ti	Mg	Pb	Sn	Al	Wa	B
Weight percentage	0.738	0.308	0.377	0.027	0.748	4.061	0.092	0.343	1.207	88.73	0.027	2.807

2. Experimental Methods

The as-cast aluminium-4% titanium alloy rod with chemical composition shown in Table 1 was cut and machined at ambient temperature into standard tensile and hardness samples. The samples were then subjected to annealing, normalising, quenching, and tempering processes before tensile and hardness tests were conducted on them. During annealing, the sample was heated to 500°C, held for one hour, and allowed to cool in the furnace. For the normalised and quenched samples, the samples were heated to 500°C, held for one hour, and allowed to cool in air and water, respectively. The tempered sample was heated to 500°C, held for one hour, quenched rapidly in water, reheated to 100°C, held at this temperature for one hour, and then allowed to cool in air. The corresponding heat treated samples were designated as “as-cast sample (AC),” “annealed sample (AS),” “normalised sample (NS),” “quenched sample (QS),” and “tempered sample (TS).”

Tensile test was carried out in accordance with ASTM E8 on standard samples using Instron Universal Tester, model 3369. Hardness test was done using a Vickers microhardness tester model “Deco” 2005 with a test load of 490 kN and a dwell time of 10 s. A minimum of 3 indentations were made on each of the samples. Standard microstructural test pieces were prepared and ground using emery paper with grit 220 to 600 microns in succession. The ground surfaces of the pieces are polished using a mixture of alumina and diamond paste and then etched in a solution containing 5 g of sodium hydroxide (NaOH) dissolved in 100 mL of water. The etched surfaces were left for 20 seconds before being rinsed with water and dried. The samples’ crystals morphologies were viewed under a Digital Metallurgical Microscope at $\times 200$ magnification and the photomicrographs are shown in Plates 1–5.

3. Results and Discussion

The tensile and yield properties of the as-cast rod samples with 4% titanium after heat treatment are shown in Figure 1. The heat treatment programmes have no significant influence on the tensile strength of the samples. When strength and ductility are important, the quenched sample possesses considerable strength (126 MPa) with 42% elongation while its hardness of 60 HV makes it a better candidate for engineering applications requiring a combination of these properties compared to the as-cast sample.

The rigidity of the as-cast sample is significantly affected by the heat treatment processes (Figure 2), with the tempered sample having lowest rigidity (1219 MPa). With the exception of the quenched sample in which significant increase in hardness is attained (35%, 60 HV), other heat treatment processes have little effect on the hardness characteristic of

FIGURE 1: Ultimate tensile strength and yield strength of as-cast and heat treated Al-4% Ti.

FIGURE 2: Young modulus of as-cast and heat treated Al-4% Ti.

the alloy (Figure 3). For the quenched sample, its toughness is slightly sacrificed for improved strength. The heat treatment processes employed improve the tensile elongation characteristic of the material with the tempered sample exhibiting superior (48%) elongation (see Figure 4). This result agreed with modulus of elasticity results obtained for the tested samples (see Figure 2). Thus, quenching process is preferred

FIGURE 3: Hardness of as-cast and heat treated Al-4% Ti.

FIGURE 4: Elongation of as-cast and heat treated Al-4% Ti.

to other heat treatment processes as it confers optimum mechanical properties on Al-4 % Ti alloy.

The microstructure analysis results of the heat treated samples together with the as-cast samples are shown in Plates from 1 to 5. The as-cast alloy morphology has some plate-like structure and evidence of formation of an intermetallic-like phase within the matrix of the alloy (Figure 5). This plate-like structure has been identified as aluminium-titanium intermetallics with transmission electron microscope [7] while the precipitate-like phase represents TiB_2 [8]. Previous work has shown that TiB_2 reinforcement is both thermodynamically and microstructurally stable within the aluminide matrices [9]. The mechanical properties of the samples are found to depend on the formation of aluminium-titanium intermetallics and TiB_2 precipitates within the matrix structure. During annealing, the plate-like features within the matrix grew in size, becoming larger and soft than that of the as-cast sample (Figure 6). During tensile testing, dislocation

FIGURE 5: Micrographs of as-cast Al-4% Ti alloy.

FIGURE 6: Micrographs of annealed Al-4% Ti alloy.

FIGURE 7: Micrographs of normalised Al-4% Ti alloy.

can glide easily because of the increased size of aluminium-titanium intermetallics which does not resist dislocation motion. This explains the slight decrease in strength as can be observed in Figure 1. The plate-like structure in the normalised sample when compared with the annealed sample appears to have been broken down (Figure 7) because of the fast cooling introduced. This is because diffusion process (crystal nucleation and growth) is more pronounced during annealing operation compared to the normalised heat treatment programme. In the quenched sample (Figure 8), an increase in volume fraction of the second TiB_2 precipitate

FIGURE 8: Micrographs of quenched Al-4% Ti alloy.

FIGURE 9: Micrographs of tempered Al-4% Ti alloy.

is observed. This increase is responsible for the observed increase in the hardness of the quenched sample (60 HV). Among the various reinforcing phases, TiB_2 is particularly attractive because it possesses many desirable properties, such as high hardness, low density, high melting temperature, high modulus, and high corrosion resistance [10, 11]. As reported by earlier researchers, evidence of agglomeration of TiB_2 precipitate was noted as being responsible for the observed results [8, 12]. The size of the plate-like crystals within the matrix of the alloy significantly declines with the crystals being more uniformly distributed within the matrix of the quenched sample. The improvement in hardness may also be attributed to this occurrence. The tempered sample matrix shows reduction in volume fraction of TiB_2 precipitate as well as that of the plate-like crystals in the matrix resulting in significant reduction in the hardness (44 HV) of the alloy (see Figure 9).

4. Conclusion

In this study tensile elongation of aluminum-4% titanium alloy is found to improve significantly with respect to the heat treatment processes. The rigidity of the as-cast sample is affected by the heat treatment processes, with the tempered sample having the lowest Young modulus value. When strength, ductility, and hardness are important, the quenched sample possesses considerable strength (126 MPa),

elongation (42%), and hardness (60 HV) which make it a better candidate than the as-cast sample with high strength but low ductility. The microstructure shows that the heat treatment programmes affect both the size and distribution of the aluminium-titanium crystals as well as the volume fraction of the secondary phase TiB_2 precipitates. However, the heat treatment processes do not significantly improve the alloy tensile strength.

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