Microstructural characterisation of Al–Si–xTi cast alloys

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The present paper reports the existence and morphology of intermetallic particles in Al–Si–xTi cast alloys. Near eutectic Al–Si alloys with 0, 0.1, 1, 2, and 5% Ti have been utilised for this purpose. Metallographic observations were made by the combination of an optical microscope and a scanning electron microscope. Wear tests were performed in a pin on disc tribometer under dry sliding conditions. The addition of Ti to the Al–Si alloys led to the precipitation of TiAlSi intermetallic phase. By increasing Ti content, hardness increases due to increasing volume fraction of relatively hard intermetallics.

Keywords: Aluminium, Casting, Optical microscopy, Intermetallic

Introduction

Al–Si alloys have a wide range of usage because of their low density, ease to form, good casting abilities and excellent corrosion resistance properties. This specific set of properties makes aluminium alloys suitable for automobile industry in several applications. One of the most important applications for aluminium alloys is heat exchangers in heating and cooling systems. They are also mainly used in cast form in critical components like pistons, valve lifters, cylinder liners, engine blocks, etc. These applications demand the study of techniques like pistons, valve lifters, cylinder liners, engine blocks, etc. These applications demand the study of techniques to improve the wear properties of these alloys.1–11 It is common practice to add Ti to Al–Si foundry alloys because of its potential grain refining effect. The solubility limit of titanium in liquid aluminum is situated between 0.12 and 0.15% Ti depending on the different references. However, an excess of Ti content may cause problems in the liquid metal process and defects in casting.11 due to precipitation of primary TiAlSi coarse intermetallic particles above the liquid temperature. Although there is ample information of TiAl intermetallics in the binary Al–Ti system most of them are related to the grain refining mechanism, little publication literature exists describing the formation and growth of TiAlSi intermetallics in widely used Al–Si foundry alloys.11–13 Some Al–Ti alloys are used as low resistance ohmic contacts.14 Also Ti–TiAl₃ metal–intermetallic laminate composites have potential application in airframes.15 The aim of the present study is to investigate the intermetallic phases and their effects in Al–Si–xTi cast alloys.

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Experimental

The Al–Si–xTi alloys were prepared using Al–Si near eutectic alloys (13.1 wt-%Si) and commercial Ti–6Al–4V alloys. Solidification of near eutectic Al–Si alloys with 0, 0.1, 1, 2 and 5% Ti have been realised by melting in an electrical induction furnace with a graphite crucible and casting in the metal mould. The molten metal was at 1100°C during casting process. Firstly Al–Si eutectic alloys were melted and then suitable Ti–6Al–4V pieces were added to the molten metal for obtaining different Ti containing alloys. To make all titanium solved in liquid aluminium casting temperature was chosen high. The composition of the alloys is given in Table 1. The alloys have maximum 0.2% vanadium but no effect of vanadium was reported in microstructural investigations. The hardness of as cast specimens was measured using a microhardness tester (Fischerscope H 100), and each reported value is an average of five measurements. Metallographic observations were primarily accomplished using an optical microscope and a scanning electron microscope equipped with energy dispersive X-ray spectroscopy (EDX). The analyses were performed by optical emission spectroscopy. Metallographic specimens were polished in the usual manner with final polishing being carried out by hand, using 3 μm diamond paste. The microstructures of the alloys were revealed by etching with Keller’s reagent (1%HF+1.5% HCl+2.5%HNO₃+95%H₂O). Friction and wear tests were performed in a Nanovea MT/60/NI type pin on disc tribometer, which permitted rotation of a flat specimen against a stationary pin or ball. The wear tests were carried out under 10 N load and using an AISI S2100 steel ball (5 mm in diameter).

During the tests coefficient of friction values for alloys were recorded continuously. All friction and wear tests were carried out under dry sliding conditions at room temperature of 25°C. Sliding speed and distance were kept constant at 0.1 m s⁻¹ and 1 km. The specimens were thoroughly cleaned with alcohol before and after the wear tests, and then dried with a hot air blower. The
weight loss during wear test was measured using a Precisa XB220A balance with the resolution of 0.1 mg.

**Results and discussion**

**Microstructural observations**

The microstructural observations show that alloys have regular Al–Si eutectic microstructure with addition of the TiAlSi intermetallic phases. It is reported that Ti based intermetallics can have three different morphologies (flakes, petals and blocks) depending on the solidification conditions, Ti content and the temperature history of the alloys.\(^\text{11,13}\) In this study, two different intermetallic morphologies was reported. A few petal-like particles were found in the cast Al–Si–1Ti microstructure (Fig. 1b). The flake-like particle morphology was the most common in the cast Al–Si–2Ti and Al–Si–5Ti microstructures (Fig. 1c and d). With increasing Ti content the size and volume fraction of intermetallic phases also increase.\(^\text{13}\)

**Microhardness of alloys**

With increasing Ti content the microhardness value of the as cast Al–Si–xTi alloys increases. This is a function of increase in volume of relatively hard TiAlSi intermetallic phases. Figure 2 shows the effect of Ti content in the hardness of alloys.

**Wear tests**

**Wear rates for Al–Si–xTi alloys**

The wear behaviour of the alloys is reported to be dependent on the morphology and quantity of the intermetallics in microstructure.\(^\text{16,17}\) The microstructural characteristics, namely, the morphology and size of the

| Table 1 Compositions of alloys, wt-% |
|---|---|---|---|
| Alloy | Si | Ti | Al |
| Al–Si | 13.1 | – | Bal. |
| Al–Si–0.1Ti | 13.1 | 0.1 | Bal. |
| Al–Si–1Ti | 13 | 1 | Bal. |
| Al–Si–2Ti | 13 | 2 | Bal. |
| Al–Si–5Ti | 12.7 | 5 | Bal. |

2 Microhardness values of Al–Si–xTi alloys as function of Ti content
hard second phases greatly control the sliding wear properties of the alloys. The modification of the intermetallic morphology leads to the variation of the wear rate of the alloys. 17

Where Ti content of the alloys is under 1% weight loss decreases with increasing Ti. This may be due to the morphology and distribution of the TiAlSi intermetallic particles. The petal-like particles found in the cast Al–Si–0.1Ti and Al–Si–1Ti microstructures increases the wear resistance of alloys. When Ti content is above 1% the flake-like intermetallic particles are present in the microstructure of alloys. It is reported that the wear rates of alloys with Ti content above 1% increases with increasing Ti amount. This is a result of tendency for embrittlement and microcracking caused by hard flake-like intermetallic TiAlSi phases. Figure 3 shows the weight loss and the coefficient of friction of the as cast Al–Si–xTi alloys as a function of Ti content.

Conclusions
The conclusions based on the experimental results are as follows.
1. Ti based intermetallics can have different morphologies (flakes and petals) depending on the Ti content, other alloying elements and the thermal history of alloy. 2. Ti based intermetallic phases in Al alloys also have different chemical compositions depending on other alloying elements and cooling rate of the alloy. 12
3. The petal-like particles were found in the cast Al–Si–1Ti microstructure. The flake-like particles were found in the cast Al–Si–2Ti and Al–Si–5Ti microstructures. 4. The alloys have maximum 0.2% vanadium, but no effect of vanadium was reported in microstructural investigations. To understand influence of vanadium further investigations are required. 5. The increase in the Ti content increases the hardness of the alloys by increasing the volume of hard TiAlSi intermetallics. The hardness increases from 841 HV0.1 to 1454 HV0.1 with addition of 5 wt-%Ti. 6. The microstructural characteristics, namely, the morphology and size of the hard second phases greatly affect the sliding wear properties of the alloys. 7. It was found that the weight loss of the as cast Al–Si–xTi alloys decreased with increasing Ti content up to 1% Ti. This may be due to the morphology and distribution of the hard TiAlSi intermetallic particles.
It was found that the coefficient of friction of the as cast Al–Si–xTi alloys increased with increasing Ti content.

The worn surface analyses show that the flake-like intermetallic particles causes the increase on wear rates.

If the morphology of the intermetallics in high Ti including alloys can be modified to petal-like shapes, the wear resistance of the alloys will be enhanced. More research work is necessary to understand and control the morphologies and growth properties of TiAlSi intermetallics.

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References