Wear properties of thixoformed AlSiCuFe alloys

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ABSTRACT: High-performance compressors which use low-viscosity lubricants face heavier wear problems and thus require a material more resistant to wear than the current high pressure die cast AlSi8Cu3Fe alloy in connecting rod applications. While hypereutectic versions of this alloy are expected to offer superior wear resistance, their processing via die casting is not straightforward. Semisolid processing of hypereutectic AlSiCuFe alloys offers to overcome the problems encountered in casting hypereutectic Al-Si alloys. A series of experimental AlSiCuFe alloys obtained by adding elemental silicon to the parent AlSi8Cu3Fe alloy were melted and were cooled to within 5 to 15ºC of their liquidus points before they were poured into a permanent mould in order to produce non-dendritic feedstock for thixoforming in the present work. The slugs machined from the ingots thus obtained were thixoformed after they were heated in situ in the semisolid range for 5 minutes in a laboratory press. The hardness of the thixoformed and heat treated parts were 84-96 HB and 121-131 HB, respectively. A modified Falex Block on Ring equipment was employed to investigate the wear properties of these alloys under service conditions which prevail in connecting rod applications in compressors. The wear resistance of the thixoformed near-eutectic AlSiCuFe alloy was found to be the highest. In spite of a notable increase in the hardness of the wear test samples, the T6 heat treatment did not appear to have an impact on the wear resistance.

Key words: Thixoforming, Aluminium alloys, Wear properties.

1 INTRODUCTION

High-performance compressors which use low-viscosity lubricants face heavier wear problems and thus require a material more resistant to wear than the current high pressure die cast (HPDC) AlSi8Cu3Fe alloy for the manufacture of connecting rods. High wear resistance, high strength, high hardness, low thermal expansion and reduced density make hypereutectic Al-Si alloys very competitive for this demanding application [1,2]. However, the use of conventionally cast hypereutectic Al-Si alloys has been restricted owing to their high latent heat and consequent long solidification time which results in die wear, segregation and excessive growth of primary silicon particles, and unfavourable shrinkage behaviour [3]. Since the casting temperature and heat content are relatively lower, the primary silicon is finer and uniformly distributed and the shrinkage is much less than that of a molten alloy, thixoforming may be a viable alternative to die casting. Furthermore, the die filling process in thixoforming can be controlled to eliminate porosity, thanks to the high viscosity of semisolid alloys.

Wear properties of AlSiCuFe alloys produced by high pressure die casting and thixoforming were recently investigated by the authors [4] and the performance of the latter was found to be encouraging. The present work was undertaken to identify the impact of Si content on the wear behaviourr of thixoformed AlSiCuFe alloys tested under conditions faced by connecting rods in compressors.

2 EXPERIMENTAL

A series of experimental AlSiCuFe alloys were obtained by adding 4 to 12 wt% elemental Si to AlSi8Cu3Fe (Table 1). These alloys were melted and then cooled to within 5 to 15ºC of their liquidus points before they were poured into a permanent mould in order to produce the non-dendritic feedstock for thixoforming. The slugs machined from these ingots were thixoformed into preforms after they were heated in situ between 568°C and 573°C, for 5 minutes in a laboratory press. The thixoformed preforms were finally machined precisely into wear ring test samples. A second set of thixoformed samples were heat treated to the T6 temper in an air furnace, by solutionizing at 500 °C for 1 hour, followed by forced air cooling before ageing at 175 °C for 8 hours. The hardness of the thixoformed and heat treated samples were measured in Brinel (HB) units with a load of 31.25 kg and a 2.5 mm diameter indenter.

Table1. OES analysis of the experimental AlSiCuFe alloys.

alloy	Si	Fe	Cu	Mn	Mg	Zn
1	8.52	1.099	2.940	0.171	0.153	0.975
2	12.65	1.109	2.600	0.181	0.119	0.907
3	16.32	1.056	2.934	0.171	0.140	0.953
4	19.73	1.044	2.623	0.164	0.105	0.893

A modified Block on Ring test unit was employed to identify the wear properties thixoformed alloys under conditions the connecting rods face in service. The counterface block material was a heat treated DIN 100Cr6 steel. The test chamber was continuously purged with a R600a refrigerant gas. Experiments were conducted with a contact pressure of 277 MPa under semi-submerged conditions in a mineral oil lubricant (0.007 Pa.s viscosity @ 40°C) at 75°C. Each test lasted 210 mins with an oscillation frequency set at 1.6 Hz. The extent of wear in the test rings representing the connecting rod of the compressor was estimated from weight loss measurements. The samples were cleaned ultrasonically in trichloroethylene before and after each test. An analytic balance with an accuracy of 0.1 mg was used to measure the mass of the samples before and after each test.

3 RESULTS AND DISCUSSION

The eutectic Si plates in the cast ingots are modified into compact blocky particles upon thixoforming while the aluminium solid solution matrix is rearranged into a uniform distribution of α-Al globules. Hence, various features of the cast ingots are replaced by a simple mixture of α-Al globules and predominantly compact blocky Si particles, irrespective of the Si level (Fig. 1). The Si particles are bigger and more frequent in the hypereutectic alloys while α-Al globules become smaller with increasing Si content.

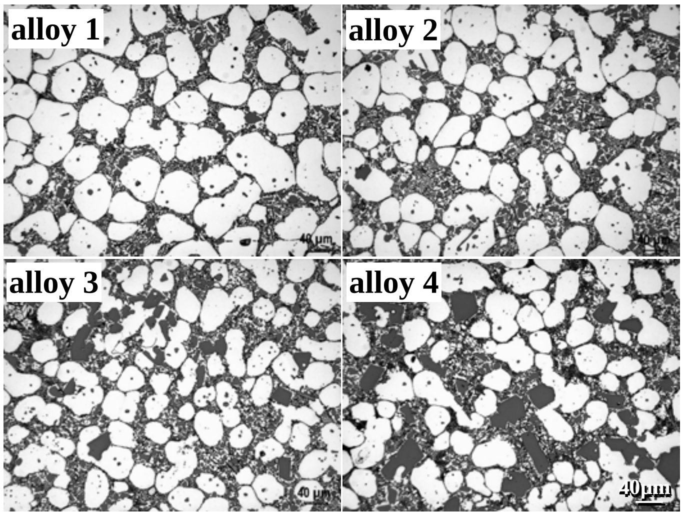

Fig. 1. Microstructures of thixoformed alloys.

With α-Al globules invariably smaller than 100μm and with no evidence of intraglobular liquid, the thixoformed microstructures are just as good as those previously reported for similar alloys [3, 5]. The solution heat treatment modified the Si particles further (Fig. 2). Fine intraglobular particles which are noted after the T6 treatment are Mg_2Si particles which have precipitated during quenching from the solution heat treatment. The hardness of the thixoformed parts which ranged between 82 and 96 HB have increased to 121-131 HB after the T6 heat treatment, increasing with increasing Si content both in the thixoformed and heat-treated states.

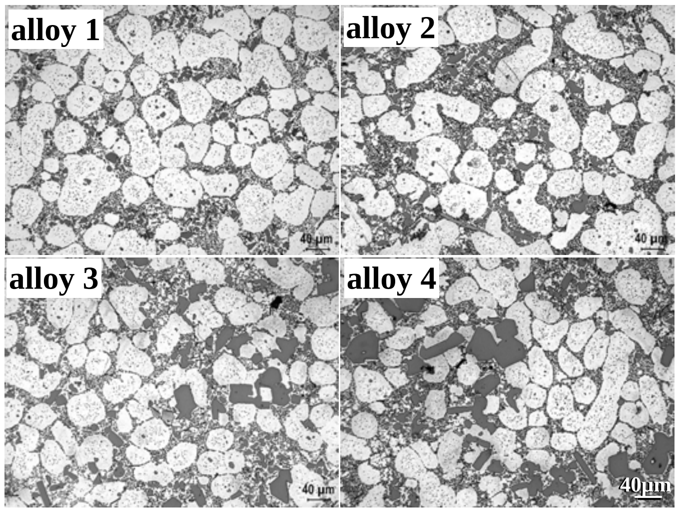

Fig. 2. Microstructures of thixoformed alloys after T6 heat treatment.

Table 2. Wear rates (k) and hardness measurements. (TF: thixo-formed; T6: heat treated)

alloy	k x 10^{-5} (mm^3/Nm)		hardness (HB)	
	TF	T6	TF	T6
1	1.201	1.058	82	122
2	0.515	0.858	85	122
3	1.001	0.915	82	127
4	1.258	1.344	85	131

The wear test results are listed in Table 2, in units of specific wear rate. The wear rates are substantial suggesting that a state of severe wear prevailed under the test conditions employed. The detailed investigation of the contact surfaces of the block and the rings has shown substantial material transfer from the latter to the counterface block suggesting that adhesive wear was occurring.

It is clear from Fig. 3 that the wear rates of the experimental AlSiCuFe alloys decrease with increasing Si content until 12 wt%. The wear resistance of the parent alloy has more than doubled with an additional 4 wt% Si. This trend is reversed, however, once the Si content increases above 12 wt% in spite of an ever increasing hardness in this composition range. Hence, of the four alloys tested in the present work, the near-eutectic alloy is the most wear resistant. A deterioration in wear properties of Al-Si alloys with increasing Si content, starting both at eutectic point and at relatively higher Si levels is reported in [6].

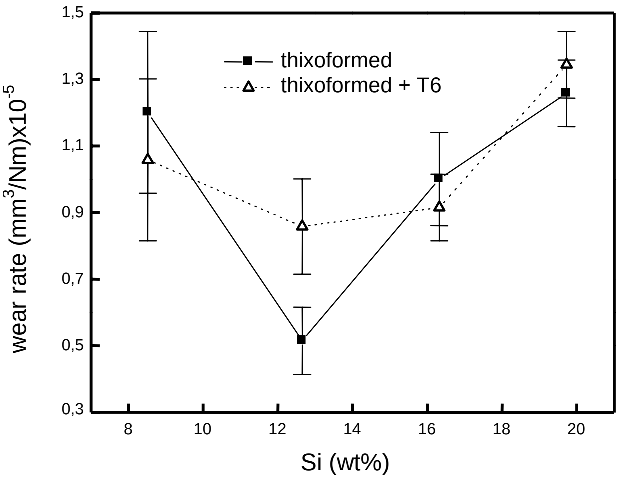

Fig. 3. Change in specific wear rates with Si content.

The wear properties in terms of Si content has been a subject of great controversy over the years [6-11]. It is suspected that the role of Si particles may be different in thixoformed Al-Si based alloys from that in conventional cast grades. Afterall, processing of Al-Si alloys is well established to impact their wear properties through its effect on Si particle characteristics [12,13]. Ward et al. [14] reported a decrease in wear resistance with increasing Si in thixoformed alloys and blamed the difficulty of thixoforming high Si alloys for their inferior wear properties. It should be noted, however, that the HPDC grade of the near-eutectic alloy (alloy 2) wears nearly 3 times more under the same conditions [4], implying that thixoforming is a viable alternative as the manufacturing route.

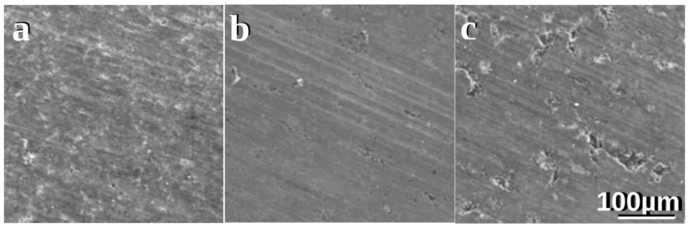

Fig. 4. Worn surfaces of (a) alloy 1, (b) alloy 2, (c) alloy 4.

The features of the worn surfaces are fully consistent with the specific wear rate measurements (Fig. 4). The hypereutectic alloy (alloy 4) shows, in addition to prominent wear marks, a heterogeneous distribution of cavities some of which are very large and deep. The vast majority of the coarse Si particles which were once perfectly embedded in the matrix are sitting inside some of these cavities fragmented. The EDS analysis has invariably shown these fragments to be Si particles.

The response of hypereutectic alloys to severe wear conditions may be linked with the debonding and fragmentation of the coarse primary Si particles. The majority of the coarse Si particles fracture and as such, can no longer be accommodated by the aluminium matrix. They eventually drop out during the wear test leaving large cavities on the surface (Fig. 5). It is thus fair to claim that the coarse primary Si particles hurt the wear performance of the thixoformed Al-Si based alloys under severe wear conditions. The fractured Si particles not only

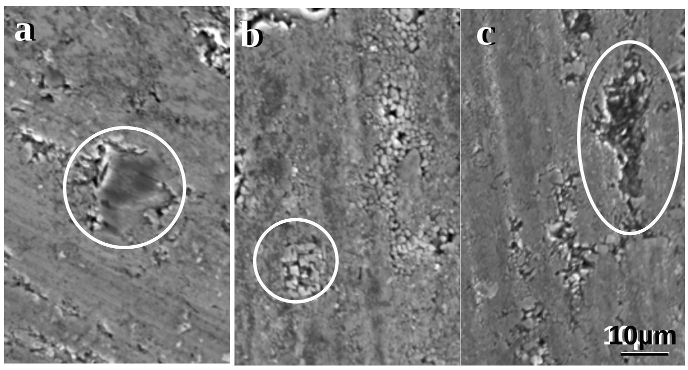

Fig. 5. Worn surfaces of (a) alloy 1, (b) alloy 2, (c) alloy 4.

contribute to the weight loss directly by dropping out from the surface but also act as abrasives and lead to additional abrasive wear. The wear performance of the hypereutectic alloys which have a higher population of coarse Si particles is thus adversely affected. This appears to be a plausible account of the inferior wear properties of the thixoformed hypereutectic AlSiCuFe alloys.

The T6 heat treatment provided considerable hardening in all alloys yet failed to improve their wear properties. The near-eutectic alloy (alloy 2), once again, is the most wear-resistant in the T6 temper. It is inferred from the performance of the thixoformed and heat treated alloys that the wear performance of the thixoformed Al-Si based alloys is governed by the size and distribution of coarse Si particles, and that the impact of hardness is only secondary. While heat treatment is reported to affect the wear resistance of Al-Si alloys, often in a favorable way [12,15], no systematic effect of heat treatment was found on the wear properties of similar thixoformed alloys in recent studies [4, 14].

4 CONCLUSIONS

Of the four alloys tested in the present work, the near-eutectic alloy is the most wear resistant. The inferior wear properties of thixoformed hypereutectic alloys are accounted for by the response of the coarse Si particles to severe wear conditions. The majority of the primary Si particles fracture and as such, can no longer be accommodated by the aluminium matrix. They eventually drop out during the wear test leaving large cavities on the surface. Having failed to change the microstructural features in an appreciable fashion, the T6 heat treatment did not improve the wear resistance in spite of increased hardness. It is inferred from the wear rates of thixoformed and heat treated samples that the wear properties of the thixoformed AlSiCuFe alloys is governed largely by the size and distribution of coarse Si particles and that the impact of hardness is only secondary.

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