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# Wear properties of high-pressure die cast and thixoformed aluminium alloys for connecting rod applications in compressors

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**Abstract**

Hypereutectic Al–Si casting alloys are attractive candidates for connecting rod applications in compressors. Several hypo- and hypereutectic Al–Si alloys were produced by high-pressure die casting and thixoforming in the present work. Hypereutectic Al–Si alloys wear less than the near-eutectic and hypoeutectic alloys under the severe wear conditions encountered in compressors, confirming the impact of Si on wear resistance. Cu also improves wear properties. The thixoformed alloys wear at comparable rates with high-pressure die cast alloys at lower Si levels, implying that the lower Si content of the former is compensated for by the thixoforming processing route. Hypereutectic compositions, uniform dispersion of fine Si particles and thixoforming as the production route are all good for a superior wear performance. The substantial hardening produced by the T6 heat treatment, however, does not translate into a sizable improvement in wear resistance of the thixoformed alloys.


*Keywords:* Thixoforming; Aluminium alloys; Casting; Sliding wear

## 1. Introduction

Forced to manufacture energy-efficient products due to environmental concerns, manufacturers of refrigerators and air conditioners have to use compressors with high-performance in their products. One of the practices to achieve better performance in compressors is to use lubricants with lower viscosity. However, low-viscosity lubricants give thinner oil films between the connecting rod and the wrist pin allowing increased metal/metal contact and heavier wear problems in connecting rods. This change in the boundary lubrication conditions in service dictates requirement for a material with superior wear properties. Hypereutectic Al–Si alloys which offer high wear resistance, high strength, high hardness and low thermal expansion [1,2], are thus attractive candidates. These attributes, together with excellent castability and reduced density, make these alloys very competitive in heavy wear applications [3]. Hard silicon particles distributed throughout the aluminium matrix are responsible for the outstanding wear resistance [3]. However, the use of these alloys in conventional cast grades has been somewhat 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 unfavorable shrinkage behaviour [4,5]. Thixoforming was recently considered to be a viable alternative in the production of these alloys, as it can help to overcome these adversities [4–6]. In thixoforming, the casting temperature and heat content are very much reduced, the time available for coarsening of the primary silicon is minimized and the shrinkage is much less than that of a molten alloy [6].

The present work originated from a need for a material more resistant to wear than the present HPDC near-eutectic Al–Si alloy for connecting rod applications in compressors. Two remedies were considered in the present work. The first was to replace the present HPDC Al–Si alloy with hypereutectic Al–Si alloys with improved wear resistance. While investigating the wear properties of several Al–Si alloys, it was judged to be worthwhile also to explore thixoforming as an alternative processing route. This paper reports the wear behaviour of hypo- and hypereutectic Al–Si alloys produced with high-pressure die casting and thixoforming, tested under conditions which prevail in connecting rod applications in compressors.

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Table 1
Chemical compositions of the alloys used in the present work

| Alloy | Route | Si | Fe | Cu | Mn | Mg | Cr | Ni | Zn |
|---|---|---|---|---|---|---|---|---|---|
| 1 | HPDC | 12.10 | 1.096 | 2.167 | 0.258 | 0.091 | 0.026 | 0.097 | 0.894 |
| 2 | HPDC | 18.21 | 0.708 | 1.988 | 0.077 | 0.456 | 0.011 | 0.509 | 0.437 |
| 3 | HPDC | 20.27 | 0.351 | 3.535 | 0.041 | 0.692 | 0.011 | 0.069 | 0.149 |
| 4 | TF | 5.86 | 0.143 | 0.006 | 0.006 | 0.172 | 0.001 | 0.003 | 0.006 |
| 5 | TF | 8.27 | 1.037 | 2.804 | 0.177 | 0.126 | 0.021 | 0.048 | 0.950 |
| 6 | TF | 14.65 | 0.307 | 3.632 | 0.010 | 0.454 | 0.003 | 0.051 | 0.090 |

HPDC, high-pressure die cast; TF, thixoformed.

Table 2
Details regarding the cooling slope casting, reheating and T6 heat treatment parameters employed for the thixoformed alloys

| Parameters | Alloy 4 | Alloy 5 | Alloy 6 |
|---|---|---|---|
| Pouring temperature (°C) | 640 ± 1 | 615 ± 1 | 585 ± 1 |
| Cooling slope length (mm) | 300 | 300 | 300 |
| Reheating temperature (°C) | 585 ± 1 | 572 ± 1 | 571 ± 1 |
| Reheating time (min) | 5 | 5 | 5 |
| Solutionizing temperature (°C)/time (h) | 540/8 | 500/8 | 500/8 |
| ageing temperature (°C)/time (h) | 170/4 | 175/8 | 175/8 |

## 2. Experimental

The chemical compositions of the aluminium alloys used in this study are listed in Table 1. The first three alloys were produced by high-pressure die casting under industrial conditions. Of these three alloys, alloy 1 is currently used in connecting rods in compressors and its performance thus serves as the reference. The next three alloys (alloys 4–6) were produced by thixoforming in the laboratory. The cooling slope (CS) casting process [7,8] was employed to produce the non-dendritic feedstock for these alloys (Table 2). Alloy ingots were melted in an electric resistance furnace set at 750 °C. The melt was then allowed to cool to the pouring temperatures between 585 °C and 640 °C. The CS casting involved pouring the molten alloys over a 50 mm wide and 500 mm long, inclined steel plate into a permanent mold with a diameter of 30 mm and a depth of 150 mm (Fig. 1). The cooling plate was adjusted at 60° with respect to the horizontal plane and was cooled by water circulation underneath and the cooling length was fixed at 300 mm for all alloys. The DSC curves covering the solidification range of alloys 4–6 are given in Fig. 2. While alloys 4 and 5 were cast with a limited amount of superheat, alloy 6 with a much higher Si content and thus a much higher melting point, was poured below the liquidus temperature, i.e. after crystallization of the primary Si has already started (Fig. 2c). This practice, recently employed for an A390 alloy [9], avoided a too high pouring temperature yet has produced a very nice as-cast microstructure dominated by α-Al rosettes.

The ingots thus obtained were sectioned into 35 mm long slugs. A medium frequency induction coil (9.6 kHz, 50 kW) placed right underneath the die was used to heat these slugs in situ, into the semisolid state. Temperature was monitored with a K-type thermocouple inserted in a 3 mm diameter hole drilled in the center of the slugs. Measures were taken to achieve a rapid heating (150 °C/min) to prevent undesirable grain growth. The slugs were then soaked at the reheating temperature for 5 min to allow spheroidization of the grains. The thixoforming operation was carried out with a laboratory press (Fig. 3). A pneumatic cylinder was used to provide the forging load (5 tonne-f max). The maximum speed of the ram was 500 mm/s and the die was pre-heated to 450 °C. The thermocouple was withdrawn from

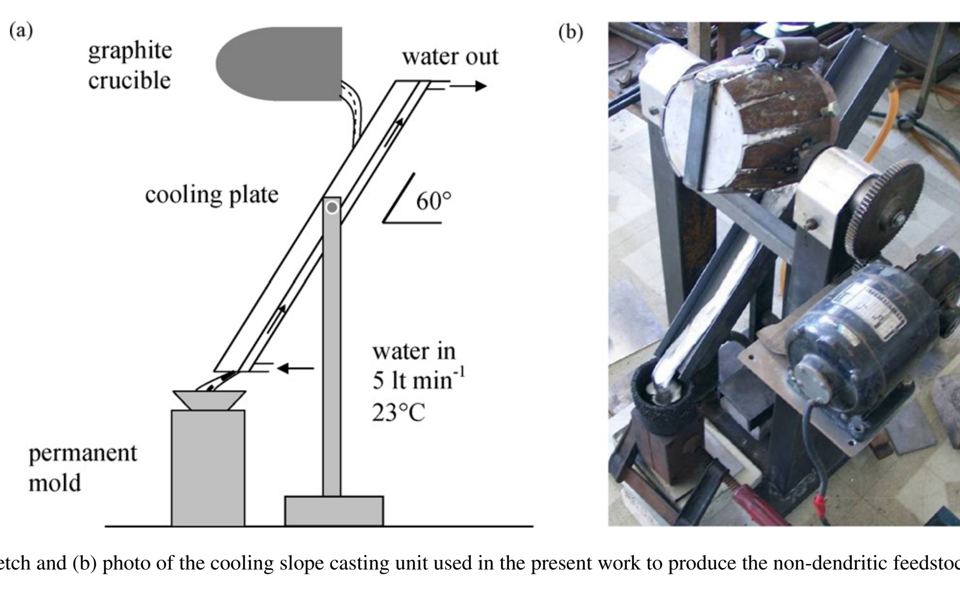


Fig. 1. (a) Sketch and (b) photo of the cooling slope casting unit used in the present work to produce the non-dendritic feedstock for alloys 4-6.