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Mechanical and wear properties of rheocast and conventional gravity die cast A356 alloy

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Abstract

A356 alloy produced by means of conventional gravity die casting and rheocasting has been investigated and their microstructure, mechanical and tribological properties were compared. The microstructure of conventional cast sample is fully dendritic in contrast to spheroidal morphology in rheocast sample. The mechanical properties of the rheocast samples are considerably higher than the conventional cast samples. The volumetric wear loss and coefficient of friction in rheocast samples are always less than those in conventional cast samples at all loads. The wear occurs mainly by ploughing mechanism.

Keywords: Rheocasting; Conventional die casting; Microstructure; Mechanical property; Wear property

1. Introduction

It is reported [1,2] that semi-solid casting processes posses many advantages over the conventional casting process. The morphology of growing solid–liquid interface in conventional casting processes is typically dendritic. The conventional casting often contains internal structural defects such as oxide and gas entrapment, shrinkage porosity that leads to poor mechanical properties. To achieve better properties, there is an increasing trend to produce common Al-alloys (e.g., A356 and A357) automotive components by semi-solid processing route [3,4]. Two casting technologies, namely, thixocasting and rheocasting, have been developed for the production of metal components by semi-solid processing route. Rheocasting process offers several advantages than the thixocasting process including reduced process complexity, increases shot size flexibility and effective solid fraction tailoring [5,6].

In the rheocasting process, molten alloy is cooled from the liquid sate to the mushy state followed by stirring the alloy during the solidification to produce semi-solid slurry, then pouring/injecting the slurry directly into the die. The formation and the evolution of non-dendritic rheocast microstructure are associated with the breakup of dendrite arms into small pieces followed by agglomeration and sintering of these pieces to form clusters [1,7]. However, the rheocasting process has been largely explored to produce complex-shaped Al-alloy components [8]. For wide application of this process in various engineering fields, the mechanical and wear behaviour of rheocast products need to be well understood.

The objective of this study was to examine the mechanical and wear behaviour of rheocast A356 alloy, which is a popular Al-alloy for automotive components. These properties were compared with those of conventional gravity die cast counterpart.

2. Experimental

In this study, commercial A356 aluminium alloy was used. The composition of the A356 alloy is given in Table 1. The liquidus and the solidus temperature of the alloy were found to be 615 °C and 538.5 °C, respectively.

The melting of the alloy was carried out in an electric resistance furnace in a clay bonded graphite crucible coated with alumina paints. After melting sufficient time was given for complete homogenisation of the melt. The melt was then degassed with dry argon.

In the rheocasting process, the melt was continuously cooled and stirred under a constant rotational speed of 320 rpm using a

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Table 1
Composition of A356 alloy used for the present investigation

	Element								
	Si	Mg	Mn	Fe	Ni	Ti	Zn	Sr	Al
wt.%	7.22	0.45	0.01	0.15	0.016	0.13	0.04	0.01	Balance

mechanical stirrer type rheocaster with bottom pouring arrangement. The average cooling rate during stirring was about 4° min^{-1}. When the temperature was reached about 580 °C, the rheocast slurry was poured in a cast iron rectangular type mould of dimension 20 mm × 100 mm × 300 mm.

Conventional gravity die casting, poured from 30 °C above the liquidus temperature, was also made in the same mould, for comparison purposes. The samples were cut from the middle of the rectangular plate for structural and mechanical properties investigations. The polished samples were etched with modified Keller's reagent (2 cm^3 HF, 3 cm^3 HCl, in 175 cm^3 H_2O) for microstructure examination.

The plate type castings of both conventional and rheocast samples were cut into thickness of approximately 10 mm for hot (300 °C) rolling. The rolling was carried out in a four high mill with reverse rolling facilities. Tensile specimen from as cast and rolled sheet were prepared as per sketch given elsewhere [9]. The specimens were tested at a strain rate of $8.3 \times 10^{-4}\,s^{-1}$. The fractured surfaces of the specimen were examined under scanning electron microscopy (SEM). The Vickers hardness of conventional and rheocast samples were taken using a load of 5.0 kg.

The sliding wear tests were carried out using a pin-on-disc machine. The pins of 8 mm diameter and 40 mm length were fabricated from 20 mm plate and made to slide against a low alloy steel disc (material: 103 Cri-Eng-31HRS60W61, equivalent to AISI 4340) of diameter 215 mm and hardness 62 Rc. The track radius and the disc speed were maintained at 55 mm and 350 rpm, respectively, to maintain at constant sliding velocity of 2.0 m/s. Three loads, namely, 19.6 N, 29.4 N and 49.0 N were applied for each test materials. Tangential force and hence, the coefficient of friction were measured continuously with an electronic sensor attached to the machine and recorded. Frictional force in kg and cumulative wear loss in μm were measured from the sensor output as a function of time. The wear test was carried out for a total sliding distance of about 2.4 km. The specific wear of the pins, defined as the cumulative volumetric wear loss suffered by the pin per unit sliding distance per unit load [10,11], were calculated from the cumulative wear data. Wear tests were carried out at room temperature without any lubrication. After the completion of wear test, the Vicker's hardness of the worn surfaces of each pin was measured under a load of 5 kg. The worn surfaces of pin samples were examined under SEM to understand the wear mechanism.

3. Results and discussion

Fig. 1a and b shows the optical microstructure of as cast ingots (both conventional gravity die cast and rheocast) solidified in the cast iron plate mould (average cooling rate 10 °C/min). As cast microstructure of both castings show that phases are uniformly distributed. The figures clearly show a morphological change in the microstructures. In conventional cast sample, the microstructure is fully dendritic whereas in rheocast sample, the primary dendrites are fragmented due to mechanical stirring. Fig. 1b clearly shows that some grains are nearly spherical and some are agglomerated together to form a bigger grain. The primary Al dendrites are plastically deformed during rheocasting processing. However, with the continued stirring, the plastic strains within the fragmented grains would be considerably less and process of coarsening or ripening will start. Since the coarsening/ripening is driven by interfacial energy [12,13], the process will lead to a reduction in the surface area and eventually spheroidal morphology is obtained. It was observed that

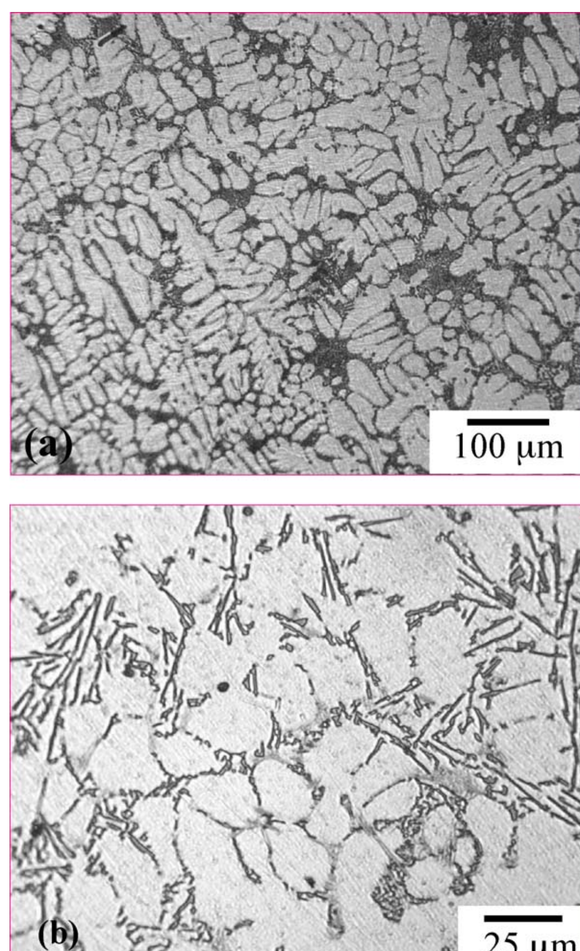

Fig. 1. Optical microscopy of as cast: (a) conventional cast and (b) rheocast A356 samples.