Effect of the casting process variables on microporosity and mechanical properties in an investment cast aluminium alloy

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Abstract

The casting process variables considered were the shell mould preheat temperature, the pouring temperature and the melt hydrogen content. The paper reports progress on a programme to appraise and optimise the mechanical properties of selected investment castings. The influence of shell preheat temperature, pouring temperature and melt hydrogen content on microporosity and mechanical properties were studied in this paper. Shell preheat temperature and melt hydrogen content are the most important process parameters determining the amount of porosity. All three parameters affect the mechanical properties to varying degrees. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Over the past 25 years, aluminium alloy investment castings have been used extensively in many applications primarily because of their excellent characteristics. The market is essentially the aerospace and defense equipment manufacturers. Traditionally, aluminium alloy investment castings have been used as the materials best suited to achieve an acceptable combination of lightness, strength and low cost. This has led to continuous developments in aluminium alloy investment castings.

The main requirement of the present work is to optimise the mechanical properties (ultimate tensile strength, yield strength and elongation or ductility) of investment castings. The hypoeutectic Al–Si casting alloy has been selected for study, which was carried out to: (1) establish the melt hydrogen content and microporosity relationships; (2) determine the effect of melt hydrogen content on mechanical properties in an investment cast alloy; and (3) examine the process variables determining the microporosity and mechanical properties. The process variables considered were the shell mould preheat temperature, the pouring temperature, and the melt hydrogen content.

2. Experimental procedures

The experimental material was hypoeutectic Al–Si alloy in the form of pre-alloyed ingots. The chemical composition of the selected alloy is shown in Table 1. About 10 kg of alloy was melted in a clay-graphite crucible using an electric resistance furnace. Various hydrogen levels were obtained by degassing and regassing. Degassing was by means of bubbling dry argon using a graphite tube, whilst regassing was carried out by stirring the melt with a graphite rod, or slowly inserting moistened refractory materials into the melt. The melt hydrogen content was controlled to the following three levels: 0.1, 0.2 and 0.3 ml/100 g Al.

2.1. Ceramic shell moulds

The ceramic shell moulds were processed using colloidal silica as binder a −200 mesh molochite was used as slurry filler and a −30 + 80 mesh molochite was applied as stucco. The wax was melted and injected into an aluminium die to form the wax patterns of the test specimen. After the first slurry coat had been applied, the remaining ceramic coat was applied to the assembled wax tree as a whole using regular procedures. The total ceramic shell mould thickness was kept at 6–8 mm. Shell moulds were poured at ambient temperature, 100 and 300°C. The pouring temperature was varied at 700, 730 and 760°C. For each shell mould preheat and hydrogen level, three moulds were poured, each at a different temperature.

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2.2. Porosity estimation

To derive porosity estimates from density values the density of the perfectly sound material had to be known. Since published data on the densities of the aluminium alloy was not sufficiently exact to be of any use, the technique adopted was to choose a casting which was observed from the X-ray radiograph to be as sound as possible. The measured density of this casting was then known to be close to that of sound material. However, to make a final small correction to obtain a highly precise final estimate, the amount of porosity in the worst region of the casting was then found by sectioning and measuring pore areas in this worst region. The measured density of the nearly sound material was then corrected upwards slightly to represent a best close estimate of the density of the perfectly sound material. The density of all the test castings was determined by weighing the castings in air and water.

The amount of porosity in a test casting was quantified by the following relation:

\[ \text{Porosity} = \frac{\text{alloy density} - \text{casting density}}{\text{alloy density}} \times 100 \]

3. Results and discussion

3.1. Porosity formation

1. Effect of hydrogen content on microporosity: it was obvious that the amount of porosity was a strong function of hydrogen level, i.e. the porosity increased with increasing amounts of dissolved hydrogen (as shown in Fig. 1). When the melt was degassed from 0.2 to 0.1 ml/100 g Al, the porosity decreased by 40–50%. When the hydrogen in the melt increased to 0.3 ml/100 g Al, the

![Fig. 1](image1.png)

Fig. 1. The effect of hydrogen content and shell temperature on porosity at pouring temperatures of (a) 700°C, and (b) 760°C.

![Fig. 2](image2.png)

Fig. 2. The effect of pouring temperature and hydrogen content on porosity at shell temperatures of (a)100°C, and (b) 300°C.
porosity increased by 45–70%, depending on the shell temperature. Thus degassing was clearly the best way to reduce porosity in Al–Si investment casting alloys.

2. Effect of pouring temperature on microporosity: it was found that the pouring temperature within the limited range investigated had a small only effect on the porosity (as shown in Fig. 2). There was generally a slight increase in porosity with pouring temperature, which seemed more apparent at high hydrogen content.

3. Effect of shell temperature on microporosity: it was found that shell temperature had a considerable influence on porosity in the given investment castings (as shown in Figs. 1 and 2). This effect was especially pronounced at higher hydrogen levels. The shell temperature effect was less for low and high hydrogen level (≤0.05 and >0.35 ml/100 g Al) from 100 to 300°C. This could be explained in terms of hydrogen evolution. At low hydrogen levels the amount of evolved hydrogen was limited by the dissolved amount, while at higher levels it was limited by the solidification time.

3.2. Mechanical properties

1. Effect of porosity on mechanical properties: the following observations were apparent from the results (as shown in Figs. 3 and 4):

1.1. There was a general decrease in UTS (Ultimate Tensile Stress) with increasing porosity. This is more pronounced for high shell preheat temperatures (300°C).

1.2. There was a moderate tendency for 0.2% PS (0.2% Proof Stress) to decrease with increasing porosity content. This is more apparent for shell moulds at 300°C, probably due to the high porosity.

1.3. The percentage elongation appears to be little affected by the levels of porosity experienced in the investigation.

The general effect of porosity in any casting is to decrease the mechanical properties. The UTS and 0.2% PS were observed to decrease at low cooling rate for low shell preheat temperatures, and at high cooling the rate for high shell preheat temperatures. One possible explanation for the difference in behaviour is that porosity formation tendency increased with shell preheat temperature.

2. Effect of pouring temperature and shell preheat temperature: the combined effects of three shell preheat temperatures and three pouring temperatures on the tensile properties are shown in Figs. 3 and 4. The following results can be observed from these figures:

2.1. The tensile properties are decreased with increasing shell temperature.

Fig. 4. The effect of pouring temperature and shell temperature on 0.2% PS at different hydrogen content: (a) 0.1; and (b) 0.3; ml/100 g Al.
2.2. Increasing the pouring temperature has a moderate effect on the UTS at low shell temperature (ambient and 100°C) while at high shell temperature (300°C) the pouring temperature significantly reduces the mechanical properties.

2.3. It seems that there is no clear correlation between 0.2% PS and pouring temperature.

2.4. The pouring temperature has little effect on the percentage elongation. The highest registered elongation was at 100°C shell temperature.

2.5. Low shell and low pouring temperatures generally produced high tensile properties.

4. Conclusions

From the experimental results and analysis in this work, the following major conclusions can be drawn:

1. The shell preheat temperature and hydrogen content are the most important process variables determining the amount of microporosity in the investment castings. The porosity is increased by increasing the shell preheat temperature and hydrogen content.

2. Low shell and low pouring temperatures generally produced high mechanical properties.

Further reading

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