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EFFECTS OF SECTION THICKNESS ON THE OPTIMUM PROPERTIES OF Al-8% Si ALLOY SQUEEZE CAST COMPONENTS

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ABSTRACT

This study was conducted to produce squeeze castings, determine the effects of section thickness on the optimum properties of squeeze cast products from Al-Si alloy. Squeeze castings with section thickness ranging from 8 to15mm and aspect ratio (height-to-section thickness ratio) not greater than 3.125:1 were made from Al-8%Si alloy using squeeze pressures of 125MPa with the alloy poured at 700°C into a squeeze die preheated to about 250°C. A lubricant made of 10% graphite in lubricating oil was used to ease ejection of squeeze castings from the die. Squeeze time was 30s. The study found that a small deviation of ±2.0mm from the nominal size of 10.0mm has no significant impact on the optimum mechanical properties of squeeze castings. However, a large deviation of +5.0mm from the nominal size significantly reduced the optimum mechanical properties of the squeeze castings.

KEYWORDS: Squeeze casting; Porosity; Alloy; Thickness.

INTRODUCTION

Squeeze casting, compared with traditional sand casting which dates back to about 2000-3500B.C. (Amstead *et al*, 1979 and Rao, 1992) is a relatively new casting technology. It is a technology with very bright future, based on its applications and advantages. Yue and Chadwick (1996) described squeeze casting as a casting process in which molten metal is solidified under the direct action of a pressure that is sufficient to prevent the appearance of either gas porosity or shrinkage porosity as opposed to all other casting processes in which some residual porosity is left. They further observed that the process is also known, variously as liquid-metal forging, squeeze forming, extrusion casting and pressure crystallisation. Squeeze casting is also called liquid pressing (Clegg, 1991).

Squeeze casting has a number of advantages which have been discussed in some studies (Lynch *et al*, 1975a; Rajagopal, 1981; Franklin and Das, 1984; Mortensen *et al*, 1989; Zhang *et al*, 1993; Yue and Chadwick, 1996). Some of the advantages include elimination of gas and shrinkage porosities, which promotes the widespread use of squeeze casting for manufacturing metal-matrix composites by infiltration (Yong *et al*, 2003; Yong and Clegg, 2004); reduction or elimination of metal wastage due to absence of feeders or risers; ability to cast both cast and wrought alloys; possibility of manipulation of process parameters to achieve the required optimum parameters.

Squeeze casting is a very important manufacturing process, which combines the advantages of forging and casting and it is used for the production of a wide range of products from monolithic alloys and metal-matrix composites parts. Such parts include vane, ring groove reinforced piston, connecting rod, M6-8 bolt, joint of aerospace structure, rotary compressor vane, shock absorber cylinder, diesel engine piston, cylinder liner bearing materials, etc in automobile, nuclear, aeronautical components, sports industries (Bracke *et al*, 1984; Li and Mc Cartney, 1994; Abubakre, 2001).

Despite its recent discovery, squeeze casting has witnessed a lot of development in type and variety of materials cast and quite a number of research studies have been carried out to improve the process particularly in the areas of molten metal metering and metal movement system during pouring into the die, lubrication systems and the use of reinforcement. However, in spite of all these researches, it has been observed that squeeze casting, particularly the relationship between the design of components (articles), the process parameters and the quality of the squeeze cast components was yet to be fully understood. Hence the need for more studies for better understanding of the process (Office of Industrial Technologies, 2000). This study was carried out to determine the effects of section thickness on the optimum properties of aluminium-silicon alloy squeeze cast products with aspect ratio (height-to-section thickness ratio) not greater than 3.125:1.

MATERIALS AND METHODS

In this study, an Al-Si alloy scrap, the composition of which is given in Table 1 and lubricant consisting of 10% graphite in lubricating oil of the type 20W/50 were used. A 2kW electric resistance furnace, die, die heater and a 150T hydraulic press were used for the study.

Series of experiments involving casting of the control shape shown in Fig. 1, with aspect ratio (height-to-section thickness ratio) of 2.5:1 and other castings with aspect ratio of 1.67:1, 2.08:1 and 3.125:1 from Aluminium-Silicon alloy were carried out using squeeze casting method. The density of the castings was determined and specimens were then prepared from the castings with the aim of determining the mechanical properties of castings by the various techniques and the results compared with each other.

Table 1: Chemical Composition of Al-Si Alloy Used

Composition, %								
Si	Sn	V	Cr	Mn	Fe	Co	Ni	Cu
8.081	< 1.980	< 0.182	< 0.110	0.173	0.686	< 0.027	0.086	1.920

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Table 1 contd.

Composition, %						
Zn	As	Pb	Zr	Nb	Mo	Al
0.511	< 0.007	0.073	0.004	< 0.001	< 0.001	Rem.

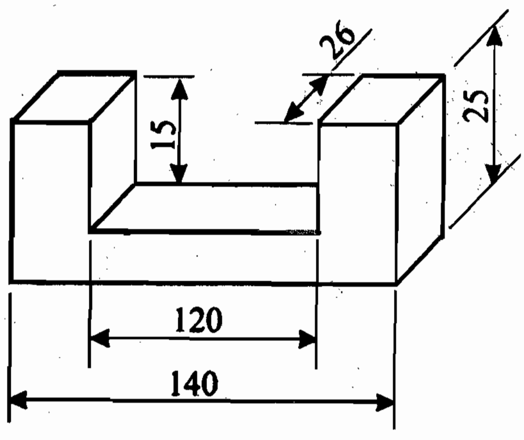

Fig. 1: Dimensions of Control Castings Dimensions are in mm.

MELTING OF ALLOY

Melting operation began with the heating of the furnace to a red-hot temperature after which required alloy was charged into a 0.3kg capacity crucible and the crucible placed inside the furnace. Fluxing was done at about 650°C by covering the surface of the already molten alloy with about 2% by weight of charge of proprietary covering flux "Foseco". The flux was then worked into the surface of the alloy to remove aluminium dross and other impurities. The resultant dross was removed leaving a very clean surface. Smaller quantity (about 1% by weight of charge) of the flux was then added for the purpose of protecting the molten alloy from the effect of the atmosphere. For the purpose of degassing of the melt, hexachloroethane tablets amounting to about 0.5% by weight of charge were used to remove dissolved hydrogen gas. The alloy was then heated to the required pouring temperature of 700°C. The temperature of the alloy was from time to time measured using the immersion pyrometer and upon attaining the required pouring temperature, the crucible was removed from the furnace and the alloy poured into a prepared die.

SQUEEZE CASTING

Squeeze castings were made using a two- part die, the lower die and the upper die (punch), made from mild steel. The lower die was mounted on a supporting bed mounted on a hydraulic press table as shown in Fig. 2. The punch was attached to the ram or plunger of the hydraulic press. The assembly was enclosed in a casing (an insulating hardboard) to isolate it from the shop atmosphere. With the door of the casing opened, the die heater was placed in between the two halves of the die. Thereafter, the door was closed. The probe for an immersion pyrometer was then placed in an 8mmØ hole located in the lower half of the die through an opening in the door.

The die surface heater was switched on to preheat the lower and upper dies. When the temperature of the squeeze casting die reached 160°C, the door was opened, the punch was raised and the heater was withdrawn from the die. A prepared lubricant made up of 10% of graphite in lubricating oil was applied on the surfaces of the die that were to be in contact with the molten metal. The heater was replaced in its position, the punch was lowered, the door was closed and the dies were then preheated to 250°C.

Thereafter, the door of the casing was opened; the punch was withdrawn upward to a position from which it could readily strike. The heater was once more removed away. Measured quantity of molten aluminium-silicon alloy of the required pouring temperature of 700°C was poured from a crucible into the lower die. The punch was then brought down with a velocity of 9.45mm/s onto the lower die and the required pressure was applied on the molten aluminium-silicon alloy for a period of 30s.

The punch was, thereafter, withdrawn upward. The solidified casting was ejected from the lower die with the help of two ejector pins. Squeeze castings were made using 125MPa with the alloy poured at 700°C. Three sets of squeeze castings were made for each section thickness (aspect ratio) of 8mm (3.125:1), 10mm (2.5:1), 12mm (2.08:1) and 15mm(1.67:1) amounting to nine squeeze castings.

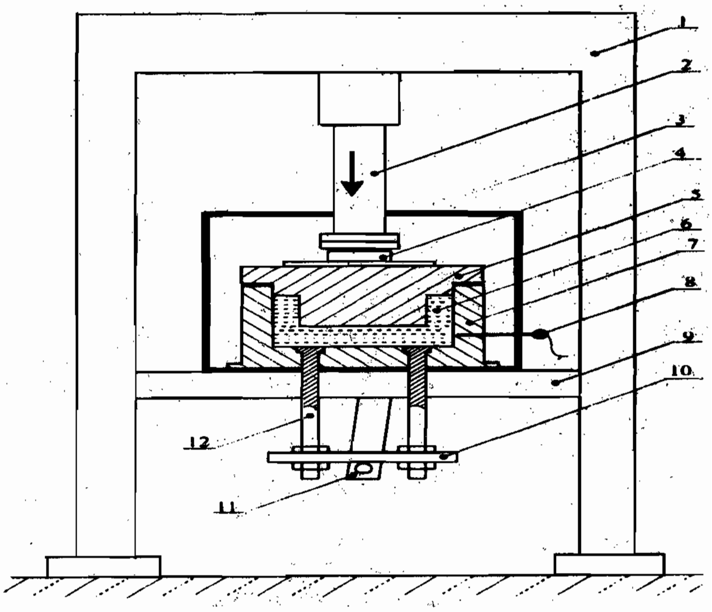

Fig. 2: Schematic Diagram of the Squeeze Casting Rig (Caster) Set Up

1. Hydraulic Press; 2- Ram; 3- Insulating Hardboard; 4- Connecting Adaptor; 5- Upper Die (Punch); 6- Molten Alloy; 7- Lower Die; 8- Pyrometer Probe; 9- Supporting Bed (Press Table); 10- Connecting Rod; 11- Ejection Hook and 12- Ejector Pin.

DETERMINATION OF DENSITY AND MECHANICAL PROPERTIES

To determine the density of the castings, castings were weighed using weighing balance. The volume of water displaced by each casting was determined with the help of a displacement can. The density of each casting was then found by dividing the mass of the casting by the volume of water displaced by it.

Tensile test was conducted on a Tinius Oslen 290 model Universal tensile testing machine with a digital 300KN capacity. The tensile specimen, made according to ASTM standard E8M-1990 for sub-size specimen (6mm) was held in the machine using wedge grips with liners for flat specimens. The specimen was gradually loaded until it fractured. During loading, the machine automatically displayed the readings and plotted the Load - extension graph.

Hardness test was carried out on a "Micromet" Rockwell type hardness-tester using an F scale. Measurements at three different locations were made and the average value of Rockwell number was noted.

RESULTS AND DISCUSSION

The results of effects of deviation from section thickness of 10.0mm of squeeze castings on the density, hardness and strength characteristics of castings made at optimum parameters are shown in Figs. 3 and 4. The density, UTS, proof stress, hardness and elongation of the control castings with section thickness of 10mm were 2.851g/cm^3, 232MPa, 156MPa, HRF58 and 3.8% respectively. These values were decreased with increase in section thickness (or decrease in aspect ratio) and vice versa. The decrease in the density and mechanical properties with increase in section thickness (or decrease in aspect ratio) are attributable to decrease in cooling rate leading to decrease in grain sizes and secondary dendrite arms as thick castings solidify more slowly than thin castings (Askeland, 1985). In all cases, the results of ANOVA showed that there were significant differences between the mean properties (UTS, proof stress, hardness and elongation) for the various section thicknesses (aspect ratios) and so section thickness (aspect ratio) has an effect.

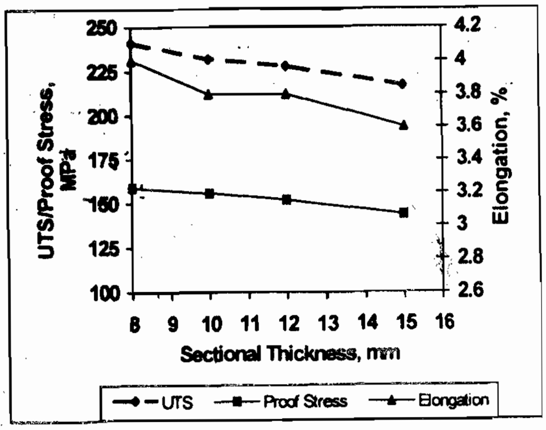

Fig. 3: The Effect of Section Thickness on Ultimate Tensile Strength, Proof Stress and Elongation of Squeeze Cast Al-8%Si Alloy

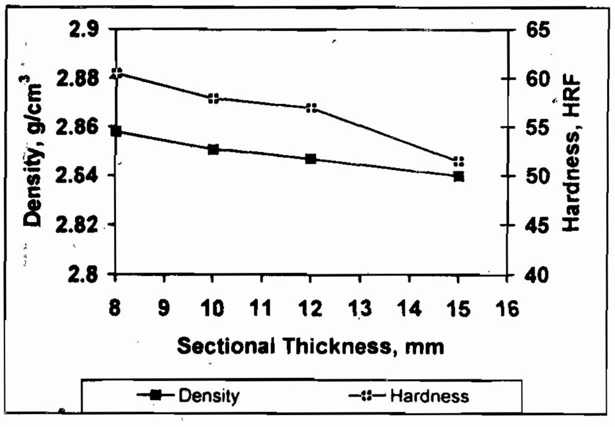

Fig. 4: The Effect of Section Thickness on Density and Hardness of Squeeze Cast Al-8%Si Alloy

However, further statistical analysis by a two tail t-test at 0.01 level of significance showed that there was no significant difference between the mean hardness values for 10.0mm (control nominal size) and 12.0mm although the differences between the mean hardness values for 8.0mm and 10.0mm and between 10.0mm and 15.0mm were significant. The differences between the mean proof stress values for 8.0 and 10.0mm and for 10.0 and 12.0mm were not significant while the difference between the mean values for 10.0mm and 15.0mm was significant. The pattern for elongation is similar to that of proof stress. For UTS the mean values for the control section thickness of 10.0mm were significantly different from the mean values for the thicknesses of 8.0, 12.0mm and 15.0mm. The differences between the mean density values for 8.0 and 10.0mm, for 10.0 and 12.0mm and for 10.0 and 15.0mm were not significant.

Therefore, variation of ±2.0mm in the section thickness of squeeze castings did not seriously affect the optimum mechanical characteristics of squeeze castings. These variations led to deviations of -4 to +9MPa in UTS, -4 to +3MPa in proof stress, -1.0 to +2.5HRF in hardness and 0.0 to +0.2% in elongation. However, a deviation of +5.0mm led to -15MPa in UTS, -12MPa in proof stress, HRF(-6.5) in hardness and -0.2% in elongation. This implies that small deviation from the nominal size does not significantly change the optimum mechanical properties of squeeze castings and small increase or decrease in aspect ratio have no significant impact on the properties of squeeze cast product. This is so because the rate of solidification in squeeze casting, like in all casting processes is dependent mostly on the rate of heat transfer from metal to the die, which in most casting processes is controlled to a large extent by resistance at the metal-mould interface. However, in squeeze casting, the squeeze pressure promotes an intimate contact between the metal and the die and this largely overcomes the resistance to heat flow (Yong and Clegg, 2004) in similar manner for thicknesses of close magnitude as the quantity of heat transferred through the die, the resistance to heat flow and hence the cooling rates are almost the same. On the other hand, a large deviation from the nominal size and nominal aspect ratio does significantly change the optimum mechanical properties of squeeze castings as the quantity of heat transferred through the die, the resistance to heat flow and hence the cooling rates largely differ for the various thicknesses.

The results of the study are applicable to squeeze castings of Al-8%Si alloys in as-cast conditions having aspect ratio not more than 3.125:1 in particular and 5:1 in general. This is because castings with higher aspect ratio may lead to entirely different characteristics, particularly for the extruded section of the casting as greater aspect ratio will involve better or additional grain refinement (Lynch *et al*, 1975b).

CONCLUSIONS

1. The density and mechanical properties of squeeze castings made at optimum pouring temperature and squeeze pressure decrease with increase in section thickness (or decrease in aspect ratio).
2. A small deviation of about 20% from nominal section thickness does not seriously affect optimum mechanical properties of Al-8%Si alloy squeeze cast products having an aspect ratio (height to section thickness ratio) not more than 3.125:1.
3. High mechanical properties are achieved with high aspect ratio while small aspect ratio leads to low mechanical properties of Al-8%Si alloy squeeze cast products.

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