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PROPERITIES OF PRESSURE CASTING OF AN INDUSTRIAL ALUMINUM-SILICON ALLOY

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ABSTRACT

The strengthening by pressure casting has been investigated on specimens of the alloy AS7 GO3 solidified under different pressures. Tensile tests, density measurements and microstructral observations were made on the castings produced. Significant improvement in the tensile strength, soundness and elongation values are obtained for castings solidified under pressure. Improvements in the density took place by the virtual elimination of shrinkage and/or gas cavities. The strength and elongation have been considerably improved due to the elimination of cavities, modification of the eutectic and the increased volume fraction of the primary aluminum under the effect of pressure.

1. INTRODUCTION

It has been realized since long time that solidification under pressure improves the soundness and mechanical properities of castings. These improvements have been related to different effects namely; elimination of internal defects, refinement of cast structure and changes in composition and morphology of phases under the effect of pressure. [1-4].

In a recent work [5] on compocasting of Al-Si reinforced by SiC fibers, it has been demonstrated that the increase of volume fraction of fibers is associated with refining action of the matrix structure. Consequently, the properties of the composite is improved by both the addition of fibers and by the refining of the matrix as the volume added increases. The purpose of the present work is to investigate the effect of casting pressure on grain size and the properties of the matrix material used previously [5]. Moreover the work is intended to establish optimum moulding pressure for obtaining premium soundness and ultimate improvement of mechanical properties of this well known industrial alloy.

2. MATERIAL AND PROCEDURE

The material used in this study is the same matrix material used previously [5] and have the following composition:

Si	Mg	Fe	Cu	Mn	Ni	Zn	Ti	Pb	Sn
		≤	≤	≤	≤	≤		≤	≤
6.5–7.5	0.25–0.4	0.2	0.1	0.1	0.05	0.1	0.1–0.2	0.05	0.05

balance aluminium. This alloy was also chosen for its common industrial uses especially in automotive parts. Laboratory melts of 700 gm were made in a graphite crucible heated by an induction coil. About 0.4 weight percent of aluminium sroncium alloy was added to the melt for modification. The melt was then transfered and poured into the die set-up (Fig. 1) in the working position on a 65 ton hydraulic press. Prior to pouring the die was preheated to 600°C by electrical resistance (3) and was lubricated by boron nitride to prevent the adhesion of metal to the die walls. The squeeze casting piston (4) mounted to the press ram (5) is allowed to descend and press the melt at 690°C. While the die is allowed to cool by a stream of pressurized air flowing insidle a tube (3) around the mould (7). The pressure was maintained until complete solidification which was indicated by

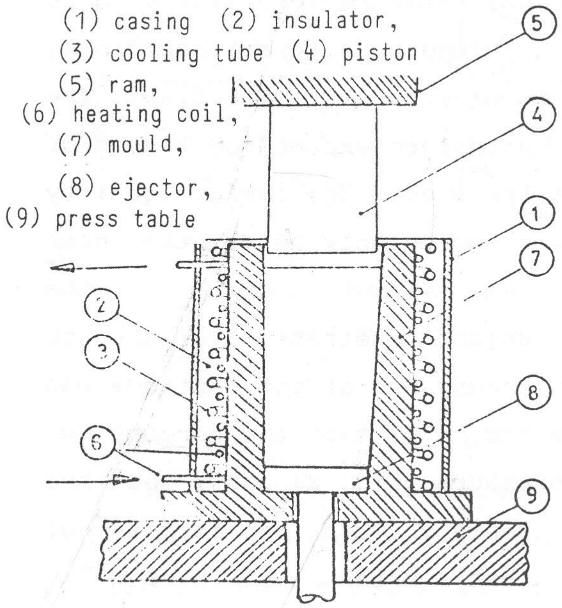

Fig. 1 Schematic drawing of pressure casting set-up.

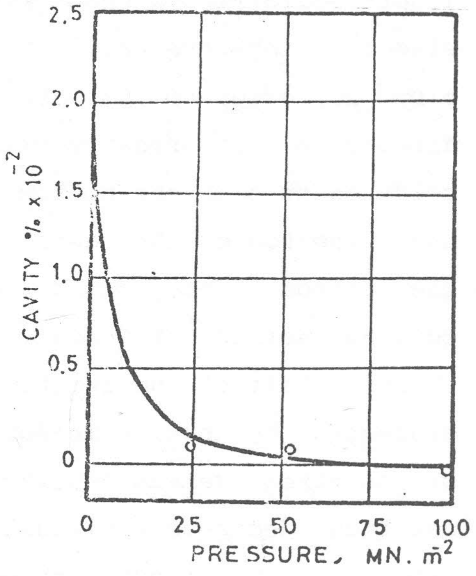

Fig. 2 Evolution of density with casting pressure

temperature recording. The squeez casting pressure was varied to include 25, 50 and 100 MN m^{-2}, while some ingots were gravity cast in the same die for comparison.

The ingots were examined carefully for signs of external defects. They were then sectioned along the longitunal axis to examine the microstructure. Density measurements were performed on specimens taken from the different ingots and tensile tests were carried out on specimens of standard dimensions.

3. EXPERIMENTAL RESULTS

Ingots solidified without external pressure were liable to be affected anywhere along their lengths with surface dross, blow holes up to 1 mm deep and other superficial flaws. The application of pressure eliminated them except for traces of cold shuts near the bottom of the ingot. The surface quality near the top of the casting was appreciably better than near the bottom. This could be explained by the coining action of pressure which penetrates over the top third to half of the ingot. The soundness of the castings was evaluated by density measurements. A plot of the percentage of cavities versus casting pressure (Fig. 2) shows that the cavities decrease initially rapidly with the increase of pressure. The fiqure shows that a pressure of 25 MN m^{-2} eliminates most of the cavities in the ingots.The application of pressure higher than 50 MN m^{-2} is associated with no appreciable improvement in the soundness. Similar results were previously reported on Zinc and steel [6] and on different aluminium alloys [7,8].

The macrostructural evidence obtained by sectioning the ignot along the vertical axis showed that the application of pressure during solidification eliminates piping and porous areas. The effect of squeeze casting pressure on the microstructure is shown in fig.(3). The microstructures consists of primary dendrites of aluminium rich solid solution dispersed in an eutectic matrix. When solidified under pressure, the primary aluminium dendrites are finer than those found at atmospheric pressure. Figure (4) is a plot of inter dendritic spacingwith the casting pressure. It is shown by the figure that the increased

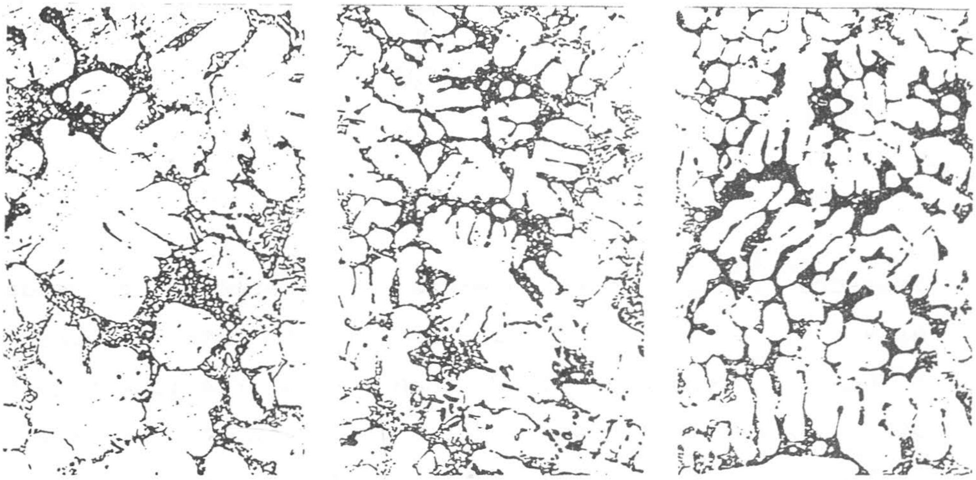
(a) (b) (c)

Fig. 3. Optical micrographs showing the structyre solidified under different pressure: (a) atmosphric, (b) 25 MNm^{-2} (c) 50 MNm^{-2}

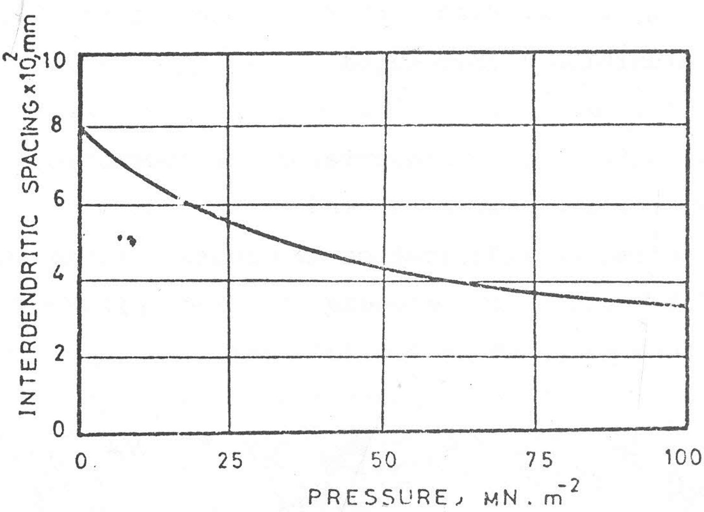

Fig. 4 Effect of casting pressure on the interdendritic spacing.

pressure reduces the interdendritic spacing to a moderate extent (i.e. by a factor of 2), the rate of decrease at higher pressure being lower than at low. Previous results on other alloys [6] showed similar evolution of grain size with casting pressure. Tensile test results for the squeeze and conventional cast alloy are plotted in figure 5. Under the selcted casting conditions, pressure yielded castings with higher strength and elongation. Both the yield strength and the ultimate strength increase with the pressure, with a decreasing rate. An increase of pressure from atmospheric to 50 MNm^{-2} increases the ultimate strength from 100 to 170 MNm^{-2}. The improvement in yield strength is lower than of ultimate strength. Beyond a pressure of 50 MNm^{-2} the curves tends to level, indicating no appreciable improvement in the strength.

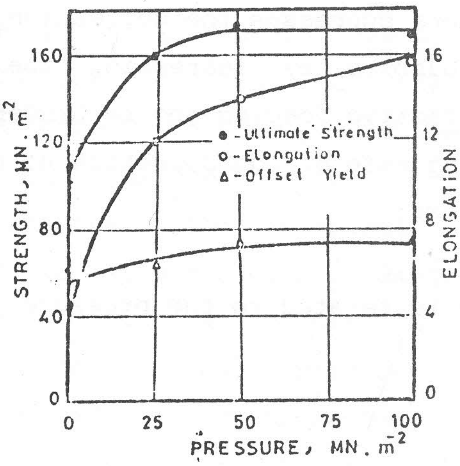

Fig. 5: Infeluence of squeeze casting pressure on the strength and elongation.

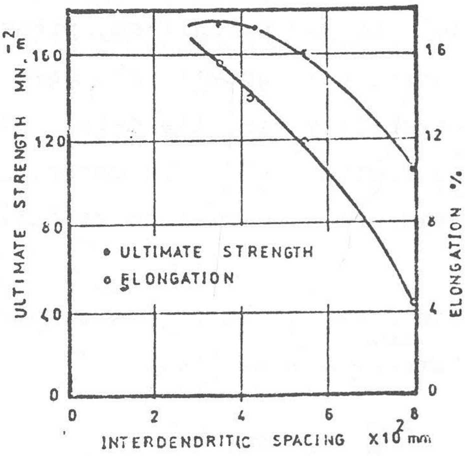

Fig. 6 Effect of interdentritic spacing on the ultimate strength and elongation.

The effect of the interdendritic spacing on the mechanical properties of the alloy is shown in Fig. 6. The latter demonstrates clearly that both the ultimate strength and elongation percent increases with the decrease of interdendritic spacing. A decrease of the latter from 80 to 35 μ m increases the ultimate strength by 70 %, while the elongation percent is increased by a factor of 4.

4. DISCUSSION

Metal consolidation was achieved by the application of pressure. The pressure helps liquid feeding to compensate for the concentrated shrinkage cavities formed towards the end of solidification process. In case of unsoundness caused due to gas porosities, pressure supresses the nucleation and subsequent growth of gas bubbles by increasing the gas solubility in the metal, effective feeding and by hindering nucleation [9]. The decreasing rate of consolidation at high pressure is explained as follows:

The free volume of the liquid is related to the pressure and temperature as [10].

$$V = Ke^{-PV_O/T}$$

where K is a constant, V_O is the true volume of the melt, V is the free volume, P is the applied pressure and T is the absolute temperature.

The equation shows that the free volume of the melt is exponentially related to the pressure i.e., the metals are far more easily compressed at low pressures than at high. The same follows from Bridgman findings [1] which show that liquids undergo much more compression over the first 2 Kilobars than over the remainder of the possible pressure range. This explains why the first increase of pressure eliminates the vast majority of porosities in the ingot. As increasing pressure is applied, their effect on the free volume dimenshes.

The mechanical properties of castings are sensitive to both the porosity and the alloy cast structure. The foundary literature has shown that the tensile properties of cast steel alloys are related to the amount of porosity present. The porosity reduces the ultimate strength and the percent reduction in area, but the yield strength is ostensibly unaffected. This explains the moderate improvement in yield strength as compared to the ultimate strength and ductility. In general, the increased rate of solidification in non ferrous alloys result in dendrities with smaller arm spacing and with a finer and more even distribution of microconstituents. Pressure applied during solidification increases the melting temperature of the alloys. Fig. 7, which is a part of Al- Si binary diagram, (taken after Markov & Tyzhikov [11] shows that a pressure of 100 MN m^{-2} increases the melting point of aluminium by 6.3 °C, reduces that of silicon by 5.8°C and causes the eutectic composition to shift from 11.7 to 14.7% Si. Moreover the α-phase field of aluminium rich solid solution is widened. In addition to its effect on the phase diagram, the pressure

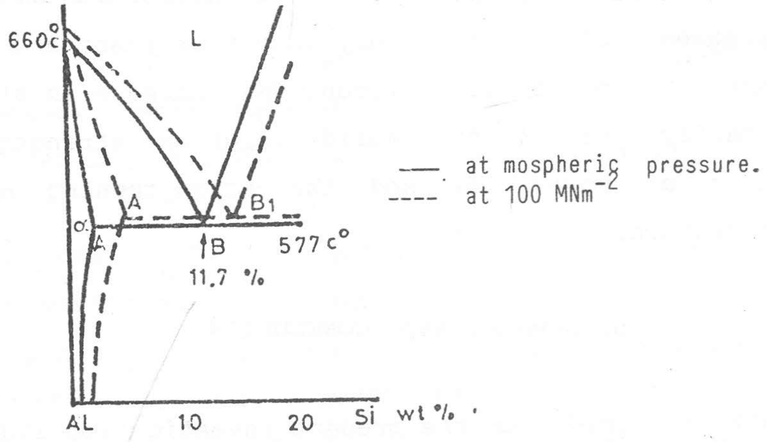

Fig. 7 Effect of pressure on the Al-Si equilibrium diagram. (Ref. 11).

applied during solidification eliminates the air gap between the melt and the mould walls. This provides a heat flow rate which is, at least one order of magnitude greater than in gravity die casting. As a result a greater degree of supercooling takes place before the onset of nucleation and a steep temperature gradient is maintained throughout the solidification process. This combined effect gives rise to the rapid cooling condition which results in the observed microstructural changes. The refining of the microstructure is not significantly enhanced at higher pressure; exceeding 50 MNm^{-2}. The reason is probably that this critical pressure is sufficient to eliminate the air gap at the die ingot interface, and higher pressure does not accelerate the solidification. The increase in solid solubility and the distorsion in the phase diagram lead to the observed increase of primary aluminium phase; however the eutectic in this case is finer and contains more silicon concentration.

The elongation is improved by the elimination of cavities, the increased volume of primary aluminium phase and by the refinement of the eutectic silicon. The increase in strength is primarily due to the solid solution strengthening, elimination of porosities and the strengthening of the eutectic mixture.

5. SUMMARY AND CONCLUSION

The results obtained from the present investigation indicates that solidification under a pressure of 25 MNm^{-2} eliminates most of the cavities in the casting. At higher pressure, no appreciable improvement in the soundness was observed. The application of pressure during solidification refined the structure of the alloy to a moderate extent. But the consequent improvements of strength and ductility are considerable. Increasing the pressure from one atmosphere to 100 MNm^{-2} increased the ultimate strength by 80% while the elongation value was improved by a factor of 4.

This improvement is significantly higher than that obtained by reinforcement of the same alloy with SiC fibers (5), in which the strength does not exceed 8-10% by the addition of 5-10 volume% fibers.

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