Jurnal Mekanikal
Disember 2003, Bil. 16, 22- 30

THE EFFECTS OF STIRRING SPEED AND REINFORCEMENT PARTICLES ON POROSITY FORMATION IN CAST MMC

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ABSTRACT

This study on porosity in cast metal matrix composite (MMC) was particular to discontinuous silicon carbide particles reinforced aluminium silicon alloy. Stir casting with three different stirring speeds and weight percentage of silicon carbide particles were applied to cast the specimens for porosity measurement. The results were measured from samples of 100, 200 and 500 rpm of stirring speed as well as from the effect of reinforcing silicon carbide particles in aluminium silicon alloy at 0, 5, 10 and 15%. Clustering particles at 100 rpm stirring speed tempted porosity formation among the reinforcement particles. At 200 rpm, the MMC contained less porosity as particles were distributed quite uniformly compared to the 100 rpm stirred sample. At 500 rpm, the MMC contained higher porosity, where entrapment of gas occurred more during stirring. However, the silicon carbide particles were distributed uniformly. Porosity presence was at least 0.09% in un-reinforced alloy stirred at 200 rpm while the highest content of porosity, 15.28%, was measured in 500 rpm reinforced specimen.

Keywords: *Aluminium-silicon alloy, silicon carbide particle, cast MMC, stir casting and porosity.*

1.0 INTRODUCTION

Porosity formation has always been associated to casting; among the preferred processing method in producing MMC. However, the formation was basically caused by the casting parameter and reinforcement particles mixed up with the matrix material. Previous works had discussed much on the effects of stirring velocities [1,2] volume fraction [3,4] and shape [5] of reinforcement particles on porosity formation in cast MMC. From several reviews of cast MMC, the causes of porosity [3] were attributed to gas entrapment during vigorous stirring, air bubbles entering the slurry either independently or as an air envelop to the reinforcement particles, water vapour (H_2O) on the surface of the reinforcing particles, hydrogen evolution and shrinkage during solidification process.

Obviously, vigorous stirring to mix the reinforcement particles uniformly in the melt matrix had introduced more gas into the slurry. The high velocity of stirring would form a vortex on the slurry surface. It was observed that development of the vortex was very helpful in assisting the particles into the matrix melt as the pressure difference between the inner and the outer surface of the melt sucks the particles into the liquid [1]. On the other hand, the vortex also trapped inclusions and somehow caused porosity formation as shown in Figure 1. From Figure 1, the original level of the slurry before the stirring process was at Line A. Line B represents the surface observed during stirring, whereas line C was the final level when the stirring stopped. The level variation was due to gas entrapment from development of the vortex.

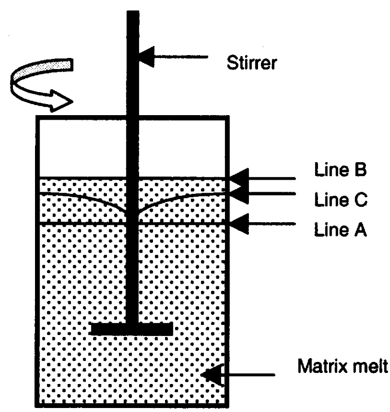


Figure 1 The effects of vortex formation on the surface of a matrix melt [1]

Further observation identified that there were presence of air envelop on the surface of reinforcement particles and air bubbles entering directly into the slurry. In most metals, the type of gas responsible for gas porosity was hydrogen. Solubility of hydrogen in liquid metal was high which caused porosity as the subsequent solidification process occurred. The presence of water vapour among the particles mentioned above was also contributing hydrogen to form porosity in cast MMC via the reaction stated below [6]:

$$H_2O\ (v) + 2/3\ Al \rightarrow 1/3\ Al_2O_3 + 2H\ (in\ Al) \quad (1)$$

As for shrinkage during solidification, there were cavity shrinkage which appeared within a casting and pipe shrinkage formed at the top of casting [6]. A faster cooling rate enabled a uniform distribution of reinforcement particles and a more rapid solidification process in cast MMC. A rapid solidification process will reduce porosity formation. Figure 2 shows the effect of cooling rate on porosity content in casting.

The effect of increasing reinforcement particles content in matrix material on porosity formation had been reviewed by many researchers. As there were air envelopes and water vapour among the particles [7], adding more particles would enhance the porosity formation. The following Figure 3 indicates the linear correlation between porosity formation and reinforcement particles. It was obvious that volume fraction of porosity increased with the incorporated alumina content. Besides, the porosity volume fraction seemed higher at the top of casting as a result of solidification shrinkage.

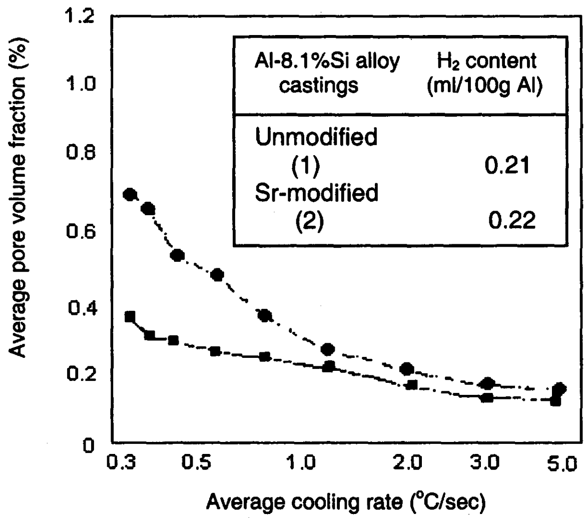


Figure 2 Average pore volume fraction as a function of average cooling rate for Al-8.1 wt % Si alloy cast [8]

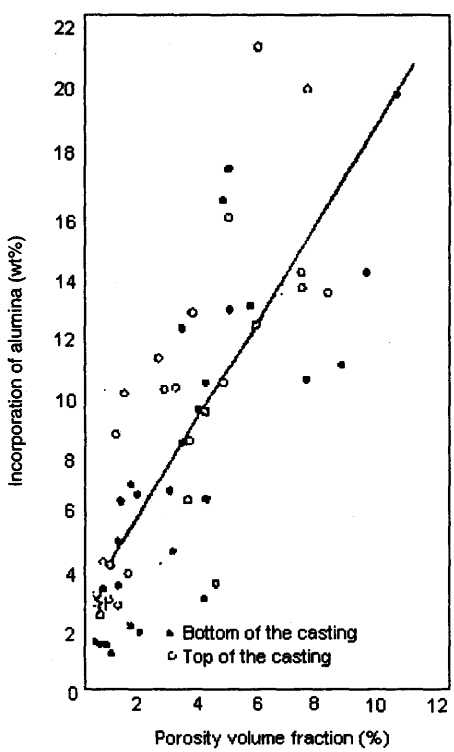


Figure 3 Variation of porosity, with alumina content in cast Al-Al_2O_3 composites [3]

2.0 EXPERIMENTAL PROCEDURE

2.1 Specimen Preparation

In this study, the cast MMCs were matrix aluminium silicon alloy with silicon carbide particles reinforcement. As mentioned in Table 1, the chemical composition of aluminium alloy indicated silicon as the main alloying element which ranged between 6.5 to 7.5%. This composition is also referred to as A356 alloy. The silicon carbide particles were in angular shape and at an average size of 20μm.

Table 1 Chemical composition of A356 (wt%)

Si	Fe	Mg	Mn	Cu	Ti	Ni	Zn	Pb	Sn
6.5-7.5	0.5	0.2-0.6	0.3	0.2	0.2	0.1	0.1	0.1	0.05

In producing the MMC specimens, stir casting was applied where silicon carbide particles and aluminium alloy were placed in an alumina coated steel crucible and held between 748-750°C for 30 minutes. The reinforcement particles were preheated along with matrix melting process. The preheating process enables the elimination of most of the water vapour presence among the particles [4,9].

After the period had elapsed, the slurry was mixed for 15 minutes. Stirring of 100, 200 and 500 rpm speeds were employed to study the effects of stirring on porosity formation. At the end of mixing time, the temperature was reduced to 710°C for pouring. The slurry was finally cast into pre-heated steel mould in the form of 20 mm x 100 mm cylinder after 2 minutes of stirring. Bottom pouring was applied to avoid inclusions and oxides formed at the melt surface being cast and hence reducing porosity formation in cast MMC. Subsequently, these cast samples were CNC machined to appropriate specimen dimensions - 15 mm length and 20 mm average diameter.

2.2 Porosity Measurement

The Archimedes principle was applied to measure the porosity content of each specimen. A graduated cylinder was filled with ionized water as the immersion fluid. The water mass dispelled which relative to the volume of particular sample was weighed using Mettler AT 400 microbalance (±100 µg). Besides, in order to obtain accurate measurement, water temperature was being considered to get the definite water density. The density deviation derived from theoretical and experimental values based on Archimedes principle [5], enable to conduct the porosity measurement as follow:

$$P = [(\rho_{th} - \rho_{exp}) / \rho_{th}] \times 100\% \qquad (2)$$

where,

P	=	porosity content (%)
ρ_{th}	=	theoretical density (g/cm^3)
ρ_{exp}	=	experimental density (g/cm^3)

2.3 Metallographic Study

Olympus PM-20 optical microscope coupled with camera system and Stereoscan 420 software controlled digital scanning electron microscope were employed to study the silicon carbide particles distribution, microstructure and porosity presence in MMC. Smooth surface and mounted specimens were prepared accordingly. To remove the scratches on the required surface, specimens were ground through a series of metallographic papers (silicon carbide grind paper) consistently starting with the coarse grit (240) and finished with the finest grit (1200). After the surface was scratch-free, specimens were polished to reveal the microstructure.

3.0 RESULTS AND DISCUSSION

3.1 Porosity Study

Porosity range in different weight percentages of silicon carbide particles and stirring speeds applied were measured and calculated using Equation (2). The deviations between measured and theoretical densities in Figure 4 were due to the presence of porosity. Measured densities were lower than the theoretical values as the stirring speed increased. At 500rpm of stirring speed, the density measured for A356/SiC/10p was as low as 2.2965 g/cm^3.

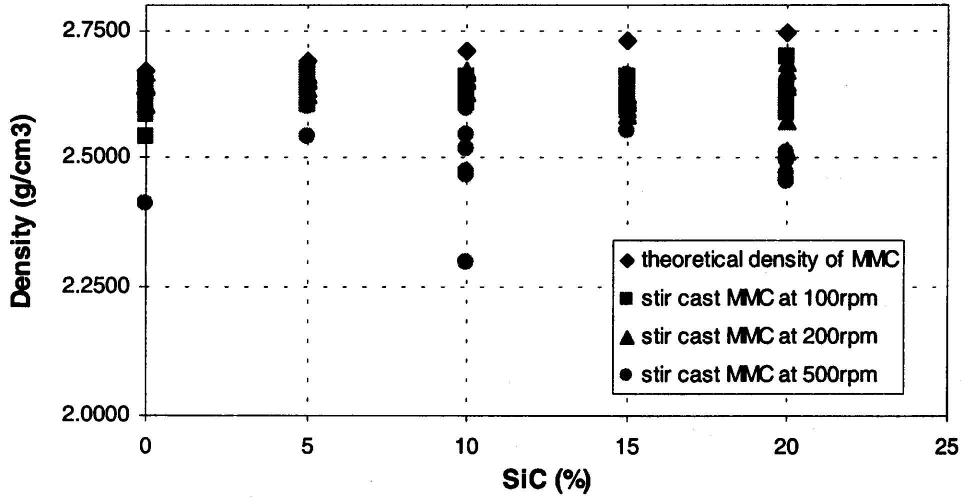


Figure 4 Density as a function of silicon carbide particle content

From observations, 500rpm of stirring speed results in increasing porosity content range. The least porosity content was 0.09% in un-reinforced A356, at 200rpm stirring speed, while the highest porosity was measured in 10% reinforced A356 and stirred at 500rpm. Figure 5 indicates a high range of porosity at 500rpm of stirring speed. At 200rpm stirring speed, the range was almost constant while the 100rpm and 500rpm stirring speeds point out porosity ranging differently; depending on the particles reinforced. Figure 5 indicates a correlation of porosity content with silicon carbide percentage reinforced in A356. At zero content of silicon carbide particle, the porosity was to be expected as there were alloy processing factors to be considered. The raw alloys was in the form of cast ingots which will develop gas porosity during processing as well.

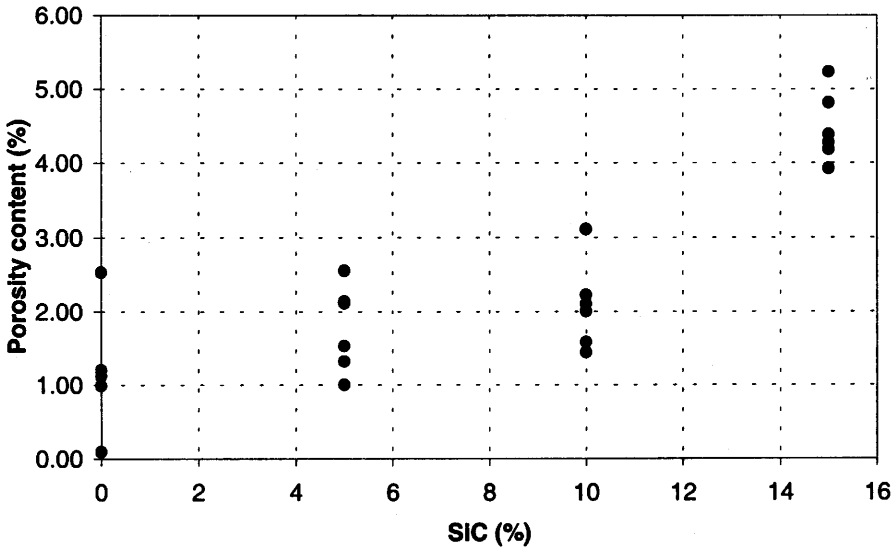


Figure 5 Porosity content as a function of silicon carbide percentage (stirred at 200rpm)

Furthermore, to expose the effect of stirring speed on porosity content in cast MMC, Figure 6 shows the increasing porosity with the increase of stirring speeds was linear. Although vigorous stirring produced a uniform distribution of particles, more entrapped gas was available in the slurry [1]. Lower stirring speed seemed to promote particle clustering and thus porosity occurred among the particles. The results indicate stirring speed influenced the entrapment of gas and inclusions. Moreover, hydrogen penetrated at liquidus state [10] of aluminium during melting process and 30 minutes of holding time, which caused gas porosity in casting. Thus, the amount of silicon carbide particles introduced into melt aluminium alloy and stirring speed had largely influenced the porosity formation in cast MMC.

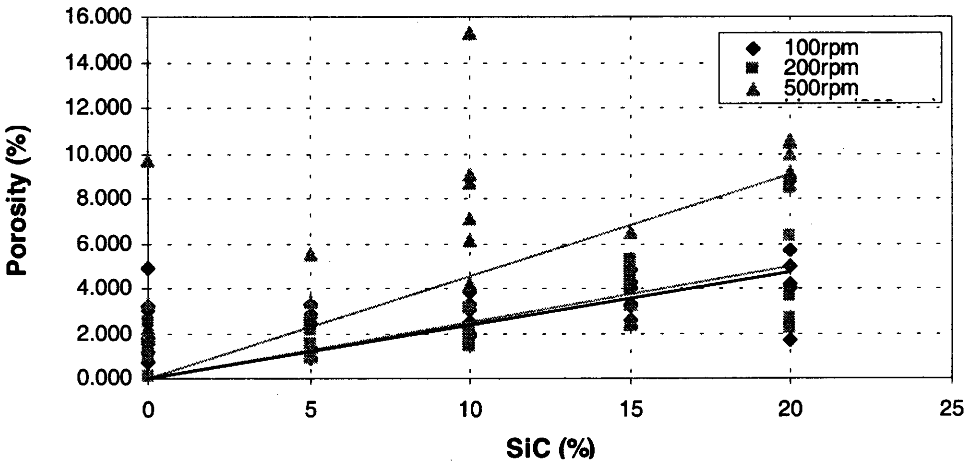
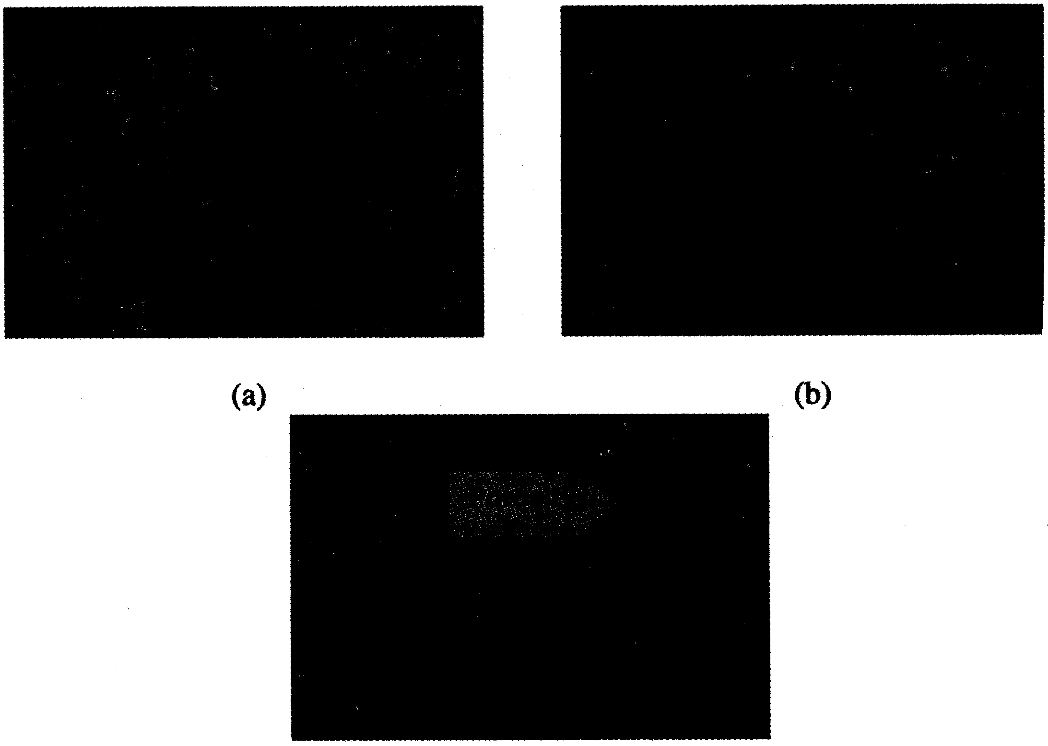


Figure 6 Porosity content of three different stirring speeds

3.2 Metallography

Optical micrographs in Figure 7 show the distribution of silicon carbide particles stirred at three different stirring speeds along with porosity presence in MMC. There was particle clustering in Figure 7(a), which indicates the effect of 100rpm of stirring speed to porosity and particle distribution. Evidently, lower speed applied to mix the particles into molten alloy was rather unsuccessful. Referring to Figures 7 (b) and (c), porosity can be observed at the particle-alloy interfaces. The high stirring speed as 500rpm had caused porosity occurrence among the uniformly distributed particles.

In un-reinforced alloy, porosity formation was probably caused by stirring process. Referring to previous work [11], round pores in 5% and 10% specimens were due to high concentration of hydrogen content. The size of porosity in un-reinforced specimen was smaller compared to the reinforced alloy which also indicates low concentration of hydrogen in the alloy. The differences that occur among the specimens were the size and distribution of porosity (Figure 7). Specimen stirred at 200rpm reveals high concentration of hydrogen via bigger size of pores, whereas in 500rpm specimen the hydrogen concentration was between high to medium [11] as the pores were long and broad. Higher hydrogen solubility in melt aluminium alloy along with reactions of water vapour present had promoted gas porosity. Though, there was solidification shrinkage observed in 100rpm specimen. In 500rpm specimen, there were long, broad pores as well as fissured type. Besides, the porosity presence among the clustering silicon carbide particles as shown in Figure 8 was also examined through scanning electron microscopy (SEM).



(a) (b)

(c)

Figure 7 Silicon carbide particle distributions in A356/SiC/20p MMC at different speed of stirring (a) 100rpm (b) 200rpm (c) 500rpm

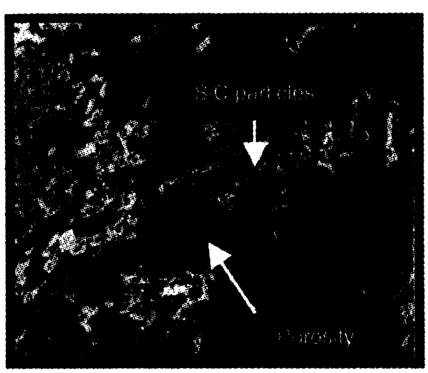


Figure 8 SEM micrograph of porosity formation within particle clustering in A356/SiC/15p MMC

4.0 CONCLUSIONS

Stirring speed for mixing purpose and volume fraction of reinforcing particles had thorough effect on the porosity of cast MMC. Application of vigorous stirring to mix the reinforcement particles was observed to increase porosity content in cast MMC as there was gas entrapment during mixing process. However, lower speed of stirring caused inconsistent particle distribution which contributed to porosity within particles clustering which occurred in most MMC stirred at 100 rpm.

Ceramic particles reinforcing in the matrix alloy were covered with air envelopes and water vapour. Pre-heating the particles prior to mixing was found to be practical in minimising porosity. Unfortunately, increasing particle reinforced in the matrix enhanced porosity formation as there were particle clustering, shrinkage, hydrogen evolution and air bubbles entering the molten alloy in cast MMC.

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