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SOLIDIFICATION CHARACTERISTIC OF TITANIUM CARBIDE PARTICULATE REINFORCED ALUMINIUM ALLOY MATRIX COMPOSITES

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Abstract

In this research solidification characteristic of metal matrix composites consisted of titanium carbide particulate reinforced aluminium-11.8% silicon alloy matrix is performed. Vortex mixing and permanent casting method are used as the manufacturing method to produce the specimens. Temperature measurements during the casting process are captured and solidification graphs are plotted to represent the solidification characteristic. The results show, as volume fraction of particulate reinforcement is increased, solidification time is faster. Particulate reinforcement promotes rapid solidification which will support finer grain size of the casting specimen. Hardness test is performed and confirmed that hardness number increased as more particulate are added to the system.

Keywords: Metal matrix composites, Aluminium alloy, Titanium carbide particulate, Solidification characteristic.

1. Introduction

In 2008, up to 4.4 million-kg of metal matrix composites (MMCs) were used globally and the number is increasing with annual growth rate at 5.9% [1]. Increasing demand of MMCs utilisations are especially for high temperature, high strength and stiffness materials such as in turbine engines and other applications. MMCs are nearly always more expensive than the most conventional materials they are replacing. Thus, MMCs are applied where improved properties and performance can justify the added cost [2].

Further study of MMCs, indicates that various solidification parameters have an effect on the microstructure and the mechanical properties of the cast metal matrix composites [3]. The properties that the composite will show during its work life are linked to the nature of the microconstituents present in the solid composite. The microstructural characteristics present in the solidified MMCs are determined in turn by the physicochemical interaction within the liquid metal and the reinforcement during processing, and by the kinetics of the phase transformations of the metal matrix, occurring during its solidification and cooling. From this, it is of main consideration to study the effect of ceramic reinforcement on the solidification kinetics and microstructural characteristics of the metal matrix [4].

Solidification is a phenomenon of latent heat liberation during the phase change of molten metal from liquid to solid during the casting process. The time required in this activity may be as short as seconds or as long as hours depending upon the casting process and the size of the casting. The microstructure composition of the metal being cast, the manner in which solidification occurs determines the ultimate microstructure and therefore properties of the casting [5].

In metal matrix composites, like the monolithic metals and alloys, the properties of the cast MMCs are largely dependent on the solidification behaviour which is dictated by the thermo-physical properties of the reinforcement, matrix materials and the mould [4]. Contemporary research on solidification of MMCs were done by Wu et al. [6], where they had found that the solidification time of primary dendrites is shortened because of the presence of the ceramic particulate. Measurement of the solidification rate reveals that the composites solidification rate which is higher than that of the base aluminium silicon alloy for the same pouring temperature. The primary dendrites of the composites are finer than those in the base aluminium silicon alloy because the eutectic silicon phase can nucleate on ceramics particulate. The eutectic under-cooling of the composites is lower than that in aluminium silicon alloy. The higher the particulate content, the shorter the eutectic solidification time [6].

Study performed by Rajan et al. [4] shows that the solidification rate increases with the introduction of particulate reinforcement, reaches a maximum and then decreases with increasing particulate reinforcement content due to lower heat transfer rates within the solidifying melt owing to the reduced effective thermal diffusivity of the composite system. Introduction of ceramic particulate reinforcement into the aluminum matrix alloy reduces the liquidus temperature. Addition of ceramic particulate reinforcement to the aluminum matrix alloy reduces the total solidification time in all the moulds studied at lower volume fractions and increases at higher volume fractions. The reduction in the effective thermal diffusivity of the composite system at high volume fractions of insulating dispersoids plays a dominant role in reducing the solidification rates.

The objective of the present study is to investigate the solidification characteristic of titanium carbide particulate reinforced aluminium-11.8% silicon alloy matrix composite. At the end, the solidification characteristic is correlated with the hardness of the MMCs under study.

2. Experimental

In this research, aluminium-11.8% silicon alloy (LM6) specimen is produced by gravity casting, and it is intended as the base of this study since LM6 is used as the matrix material. MMCs specimen with volume fractions of 5 and 15% of titanium carbide particulate (TiCp) are reinforced to the LM6 matrix. A permanent mould made from copper is used to produce the specimens during gravity casting. The mould is cylindrically shaped and specifically designed to meet the research objective which is to study the solidification characteristics. Previous researchers, such as Baez et al. [7], Rajan et al. [4], and Centin and Kalkanli [8] had used this type of shape to study the solidification of MMCs.

Reinforcing an aluminium alloy with reinforcement material produces a material that displays physical and mechanical properties of both the metal matrix and the reinforcement material. The toughness and formability of aluminium alloy can be combined with the strength of reinforcement material [9]. Aluminium-11.8% silicon (LM6) alloy is used as material for the matrix due to its very good fluidity and castability. It is an eutectic alloy having the lowest melting point as per the aluminium-silicon equilibrium phase diagram and available at reduced cost in the market [10].

Titanium carbide particulate (TiCp) mesh-325 (44 μm) is used as second phase. It has a high strength, high hardness, low coefficient of thermal expansion and density which when reinforced with metal alloys make them highly attractive materials and meet the demands in a range of engineering applications [11]. In this study, vortex technique (Fig. 1) is used for mixing the reinforcement and matrix components of the MMCs casting. Vortex method is a mixing process used to stir the reinforcement particulate and the metal or alloy matrix in the crucible. The impeller blade is selected for the necessity of turbulence required according to the mixing level. The speed of the rotating blade used in the vortex method can be controlled with the aid of a digital controller and this made possible to pour the mixture at the required viscosity and fluidity level [12].

Fig. 1. Impeller Geometry.

The mould set-up and dimension is shown in Fig. 2. The permanent mould is not pre-heated and the processing of the MMCs are carried out at a temperature of 725 ± 5^{o}C with a stirring speed of 700 rpm, mixing time 10 seconds, particle addition rate 5.276 mg.s^{-1} and 10.552 mg.s^{-1} for 5% and 15% volume fraction of TiCp respectively (Fig. 3).

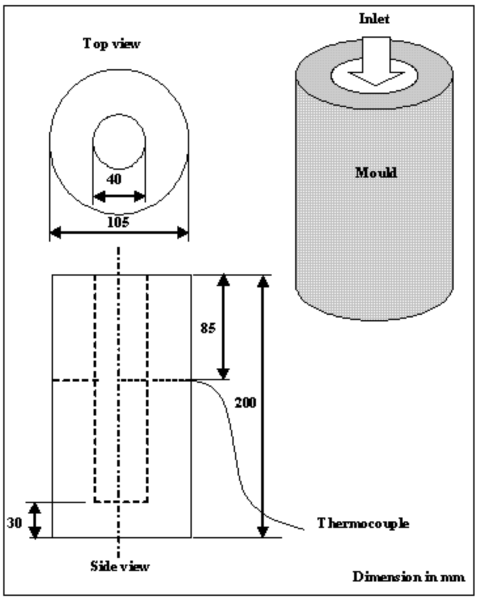

Fig. 2. Schematic Diagram of Mould Setup and Dimension.

The whole solidification process occurred after immediate pouring of the composite slurry mixture into the metallic mould cavity. The particulate present in the alloy matrix, it acts as inclusion in the melt. These particulate behave as heterogeneous nucleation sites and hence promote the solidification rate. The melt is poured at a temperature of 720^{o}C into the mould and immediately a cotton cloth is covered at the top as insulation. Fig. 4 shows the pouring of molten MMCs into the permanent mould.

Fig. 3. Vortex Mixing Technique.

Fig. 4. Pouring MMCs Melt into the Permanent Mould.

Thermal measurement during the casting process is performed inside the copper mould. A K-type thermocouple of 0.45 mm size is used to measure the temperature variation of the molten slurry MMC during the casting process. The tip of the thermocouples is located at the center, of the mould. The temperature measurements are recorded using a computer aided data acquisition system. This is done by attaching thermocouple wire to a data logger which is interfaced to a computer unit. The results from thermal measurement is solidification data which is plotted against time to obtain solidification curve for each samples containing different volume fractions of TiCp respectively.

To obtain the mechanical property, specimens are prepared for hardness test. Hardness of a material corresponds to its resistance to localised plastic deformation (e.g., wear, dent or scratch). Specimens are subjected to a Rockwell superficial hardness test. A ball indenter 1/16 inch in diameter and total load of penetration 15 kgf / 147N (HR15T) is applied to five locations in each sample and its mean value represent the Rockwell hardness number.

3. Results and Discussion

The experimental results on solidification characteristic, microstructure and hardness are discussed in the following paragraphs.

3.1. Solidification characteristic

The solidification graphs were obtained by measuring the temperature of the LM6 alloy and MMC castings during cooling and solidification throughout the casting process. The temperature measurements in the center of the casting are used as the data to plot the graphs. Graphs are plotted with the temperature as the value (Y-axis) against time as the category (X-axis). They are plotted and shown in Fig. 5. Introduction of second phase particulate into a matrix alloy usually affects the various time and temperature parameters of its solidification curve. The variation in the nature of the solidification curve always has a significant effect on the microstructure and mechanical behaviour of the material.

Examination by volume fraction of TiCp content indicates that the cooling and solidification is faster as the volume fraction of TiCp content is increased, this result is explained by nucleation sites base on TiCp which promotes solidification as more particulate are added into the system. The solidification time for volume fractions of TiCp content 0, 5 and 15% are 15, 13 and 8 seconds respectively. However, as stated in [4] that solidification rate will reach its maximum and then decreases as particulate addition increases, this will be examined on our next study, where addition of 20 and 25% of TiCp in the MMC system are to be conducted.

3.2. Microstructure

It is shown that unreinforced LM6 alloy which consists of two main micro constituents, the first is the primary phase rich in aluminium, which corresponds to the dendritic light gray matrix, the second micro constituent is the eutectic phase which present in dark gray (Fig. 6).

It is indicated that nucleation of the intermetallic and eutectic microconstituents on the TiCp, as the addition of particulate is increased the distribution of the particulate on the matrix can be seen (Figs. 7 and 8). It can be noticed that nucleation which is the development of the grain structure which is well promoted as particulate are introduced into the melt to promote equiaxed grain formation.

Faster solidification rate is promoted due to the presence of thermally insulating TiCp contents which reduce the amount of heat to be removed. Karnezis et al. [13] reported that high solidification rate gives rise to a much finer cast microstructure. The particles are less likely to be rejected by the solidification front due to the high relative velocity between the solid-liquid interface and the particles, this velocity exceeding the critical front velocity for pushing. Engulfment occurred rather than rejection of particles due to the interaction of solid-liquid interface in the high velocity. The alteration in nucleation and growth mechanism of the micro-constituent associated with the presence of TiCp acting as a nucleating agent has affected the solidification morphology present in the MMCs.

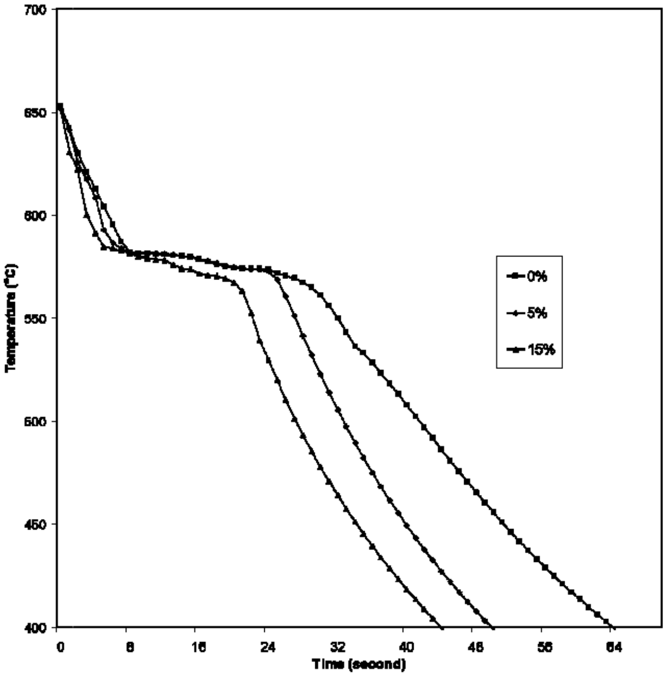

Fig. 5. Solidification Graphs of LM6 (0% TiCp) and MMCs (LM6 + 5 and 15% TiCp).

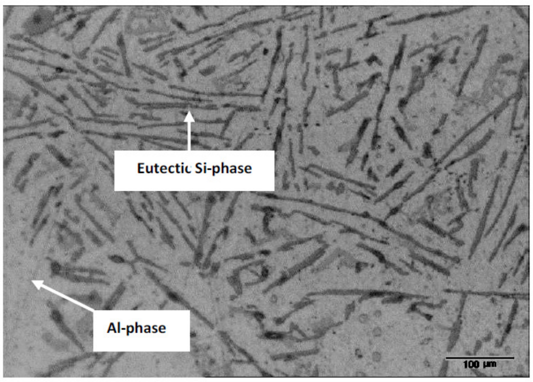

Fig. 6. Microstructure of Unreinforced LM6.

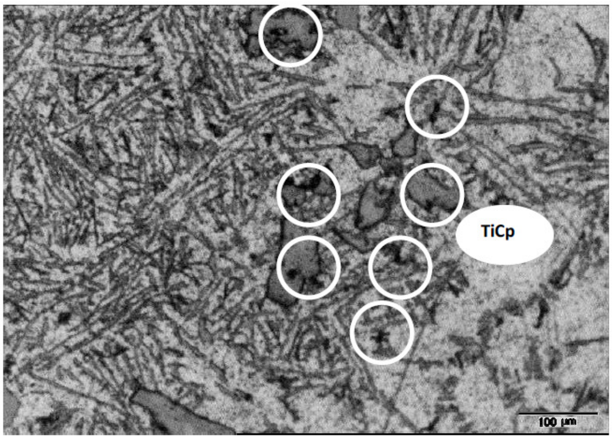

Fig. 7. Microstructure of LM6 + 5% TiCp.

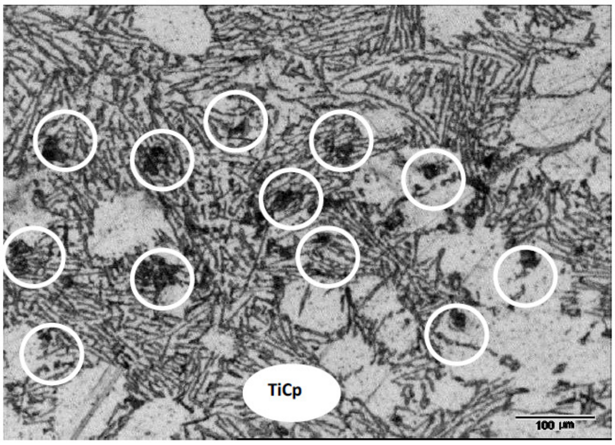

Fig. 8. Microstructure of LM6 + 15% TiCp.

3.3. Microstructure

Result of hardness test, shows that unreinforced alloy specimens have lower hardness value compared to the reinforced specimens as shown in Fig. 9. This result correlates with the faster solidification as the volume fraction of TiCp is increased. Faster solidification promotes finer grain size and better mechanical property. Also the addition of particulate reinforcement which is harder in nature has an immediate effect on the mechanical property represented by hardness number. This result is well supported by a study performed by Sulaiman et al. [14], where they had found that by increasing the addition of particulate in the aluminium matrix alloy will improved the hardness of the material. For MMCs sample solidified in copper mould for TiCp volume fractions 0, 5 and 15% the average values of Rockwell number are 51.5, 56.16 and 72.3 respectively.

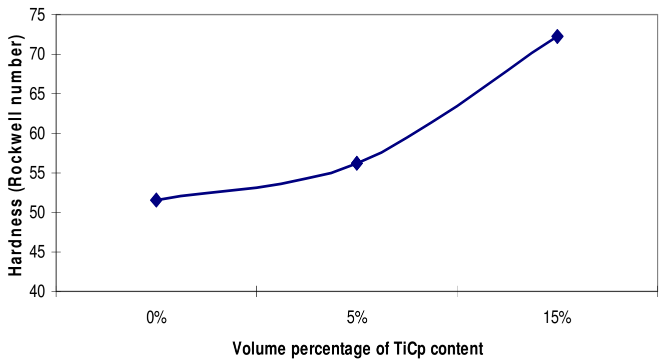

Fig. 9. Hardness Number of LM6 (0% TiCp) and MMCs (LM6 + 5 and 15%) TiCp).

4. Conclusions

The addition of titanium carbide particulate reinforcement to aluminium-11.8% silicon alloy matrix fabricated by permanent mould gravity casting has an effect on the solidification characteristics. As volume fraction of TiCp is increased, the solidification time is faster. Hardness test is performed and confirmed that hardness number increased as more particulate are added to the system.

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