Processing and characterisation of LM30 alloy + graphite reinforced composite through gravity and centrifugal casting

S. Senthil Murugan

Department of Mechanical Engineering,
Mepco Schlenk Engineering College (Autonomous), Sivakasi 626005, India

gctsegan@gmail.com

ABSTRACT. *The purpose of this study is to fabricate and characterise the aluminium matrix composite reinforced with graphite through stir casting process. Composites and Functionally Graded Composite Materials (FGCMs) are one of the potential and advanced classes of engineering materials, which exhibits gradual transitions in the microstructure and/or the composition in a specific direction leading to variation in the functional performance of a component. The objective of the present investigation is to fabricate and characterize graphite hybrid particle reinforced aluminium functionally graded composite. Gravity casting was used for making hybrid composite and centrifugal casting method was used for making functionally graded hybrid (primary silicon and graphite) composite. the results showed the movement of graphite particles towards the inner region in centrifugal cast and also showed the dendrite structure in gravity cast specimen.*

RÉSUMÉ. *Le but de cette étude est de fabriquer et de caractériser le composite à matrice aluminium renforcé de graphite par un procédé de moulage sous agitation. Les matériaux composites et les matériaux composites à gradient de fonctionnalité (FGCM, le sigle de « Functionally Graded Composite Materials » en anglais) constituent l'une des classes potentielles et avancées de matériaux d'ingénierie, qui présentent des transitions progressives dans la microstructure et/ou la composition dans une direction spécifique, ce qui entraîne une variation des performances fonctionnelles d'un composant. L'objectif de la présente étude est de fabriquer et de caractériser un composite à gradient de fonctionnalité en aluminium renforcé de particules hybrides de graphite. Le moulage par gravité a été utilisée pour la fabrication de composites hybrides et la méthode de moulage de centrifugation a été utilisée pour la fabrication de composites hybrides à gradient de fonctionnalité (silicium primaire et graphite). Les résultats ont montré le mouvement des particules de graphite vers la région interne dans le moulage de centrifugation et ont également montré la structure de dendrite dans un échantillon moulé par gravité.*

KEYWORDS: *centrifugal casting, dendritic structure, FGCMs, gravity casting.*

MOTS-CLÉS: *Moulage de centrifugation, structure dendritique, FGCMs, moulage par gravité.*

DOI:10.3166/ACSM.42.555-564 © 2018 Lavoisier

1. Introduction

Functionally graded materials (FGMs) are in their early stages of evolution and are expected to have a strong impact on the design and development of new components and structures with better performance. In the case of FGM approach, an ‘inverse design procedure’ is followed where the choice of basic material ingredients and material processes are combined with three dimensional mechanical analysis to form the graded structures and components for demanding applications (Chirita *et al.*, 2008). Composite materials and FGMs are used for insulation purposes in many applications (Saio, 2017). Even though the phenomenan of graded structures is prevalent in nature and some of the conventional engineering materials, a formulated concept of making functionally graded materials was proposed in Japan in the mid -1980s. Among the various processing routes available for FGM, such as: chemical vapour deposition, physical vapour deposition, sol-gel technique, plasma spraying, molten metal infiltration, self- propagating high temperature synthesis, spray forming and centrifugal casting. The solidification process in general, and centrifugal casting in particular is the simplest and most cost effective method for producing large size engineering components (Pradeep *et al*., 2008). Centrifugal castings are the simplest and most cost effective production method for FGMs (Nairobi *et al*., 2005). Functionally graded composite materials can be formed by centrifugal casting. In centrifugal casting, the gradation occurs mainly due to the density difference between the molten metal and unmolten phases or particles present in the system. The stir casting process has been one of the most popular methods to fabricate particulate reinforced cast composites (Rajan *et al*., 2003; Senthil *et al*., 2016). Mechanical stirrer with blades creates a vortex flow in the fully liquid alloy, and mixing of particles in the slurry. The composition or microstructure gradient is tailored by varying the processing parameters. Al-17Si - 4.5Cu (LM 30/A390) is one of the important cast alloys designed specifically for a die cast aluminium automobile engine, operating without the usual cast iron cylinder liner. Its application potentially extends to a wide range of castings where high wear resistance, and low mass are required (Murugan *et al*., 2017), and especially where advantage can be taken of the lower cost of the die casting process, e.g., pumps, pulleys, brake shoes, and air compressors.

In the present hybrid composite design, the FGCM contained hard primary silicon to improve the strength and abrasive wear resistance, and the soft graphite particles to improve the adhesive wear resistance and to act as a solid lubricant. The aluminium alloy LM30 containing 17wt% silicon was used as the matrix alloy, where the primary silicon that forms during solidification acts as in-situ reinforcement. In this study, the hybrid composites were fabricated using gravity die casting by liquid metal stir casting. The centrifugal casting method was used to make the functionally graded hybrid (primary silicon and graphite) composite. The objective of the present investigation is to fabricate through centrifugal and gravity casting methods and characterize LM30 aluminium matrix composite by the addition of graphite. The synthesized composites are evaluated using optical metallography, hardness. Finally the results were compared.

2. Experimental details

2.1. Material selection

In this study, LM30 aluminium alloy containing high silicon (17Si) was the matrix and graphite was added as reinforcement. Table 1 shows the chemical composition of LM30 aluminium alloy. Structural characteristics and hardness measurements are evaluated by optical microscopy and brinell hardness tester respectively.

Table 1. Composition of LM30 alloy in wt.%

Element	Si	Cu	Mn	Mg	Cr	Al
Weight %	16-18	4.0 -5.0	0.4-0.7	0.3 max	1.1 max	Remainder

2.2. Composites through gravity casting process

All cast metals can be cast by permanent mould die method. In this gravity die casting the metal is poured into the mould due to the gravity force. In order to evaluate the hardness and to study the microstructures of the LM30 alloy and 1 % wt magnesium reinforced with 5 % wt graphite hybrid composite, the gravity die casting is chosen to fabricate the composite casting specimen. For making the specimen, maintaining the temperature for the casting is very important. The mould is preheating at the temperature of 250°C and graphite is preheated at 400°C. At 720°C magnesium (1% wt.) is added into the molten metal. Graphite addition into the molten metal begins at the melt temperature of 725°C. Stirrer setup shown in figure 1 is used for the graphite particle addition into the molten metal. When the melt temperature reaches 730°C it is poured into the preheated mould. Figure 2 shows the composites synthesized by stir casting setup and prepared by gravity casting method.

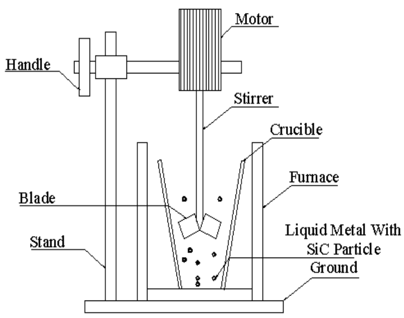


Figure 1. Schematic diagram of composite fabrication setup

Figure 2. Hybrid composite gravity casting samples

2.3. Composites through centrifugal casting process

Horizontal and vertical centrifugal casting concepts are shown in figure 3 and 4 respectively. Functionally graded composites can be formed by both above said centrifugal casting techniques through segregation of particles due to centrifugal force. In this study, horizontal centrifugal casting technique was used to fabricate composite. In order to evaluate the hardness and to study the microstructures of the hybrid composite of LM30 alloy, 5%w t. Graphite and 1% wt. magnesium the centrifugal casting was chosen to fabricate the casting specimen. Mechanical properties would be better than those of static castings due to the finer grains resulting from the process and the quality of the cast also good (Wei and Steve, 2008)

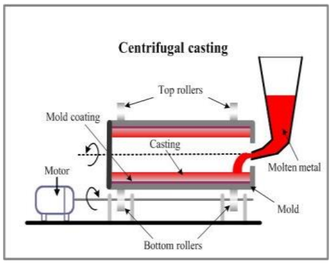


Figure 3. Horizontal centrifugal casting

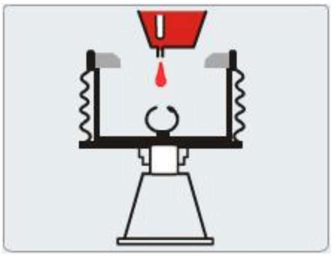


Figure 4. Vertical centrifugal casting

The centrifugal casting mould was preheated at the temperature of 300°C and graphite was preheated in oven at 350°C. If the mould wall thickness increases, solidification time decreases because of the chilling effect (Madhusudhan *et al.*, 2010). Magnesium was added at 725°C into molten metal. The Graphite was added at the melt temperature of 730°C. These processes all were done in the furnace with the stirring setup. After the composite preparation was done, the melt was poured at 780°C into the centrifugal mould run in the centrifugal machine. Figure 5 shows the prepared centrifugal cast and the graphite pattern is also visible in figure 6 on the inner side of the cast.

Figure 5. Centrifugal cast

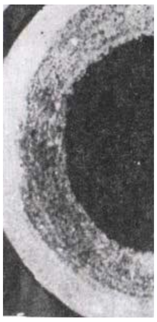


Figure 6. Distribution of graphite from outer to inner region in Al-Graphite composite

3. Results and discussion

3.1 Composite produced by gravity casting

Figure 7 (a, b) shows the optical microstructure of hybrid composite (LM30 alloy, 5% wt. graphite and 1% wt. magnesium) fabricated by stir casting and shaped by gravity casting. The different phases observed in the micrographs are: (a) the white region represents the primary aluminium (α-aluminium), (b) the dark blocky phases are the primary silicon, (c) The scattered small grey phases are the eutectic silicon phases and (d) the extreme black phase represents graphite. The particle size of primary silicon varied from 20µm to 120µm. In gravity casting the particle distribution of graphite and the primary silicon were almost uniform in the matrix. The addition of graphite refined the eutectic silicon particles and the alpha aluminium (α-Al). However the primary silicon did not show any refinement. Graphite particle were mostly associated with eutectic silicon particles which may be due to the nucleation of primary silicon particles from the graphite surface or the pushing of both the particle to the eutectic region. The dendritic shape of primary aluminum is not observed in composite, which is due to the hindrance given by the graphite particle during solidification as well as the stirring of the liquid metal during composite processing. The average Brinell hardness of the hybrid composite produced by gravity casting was 125.3 BHN, which is lower than the hardness of unreinforced LM30 which was 126.7 BHN.

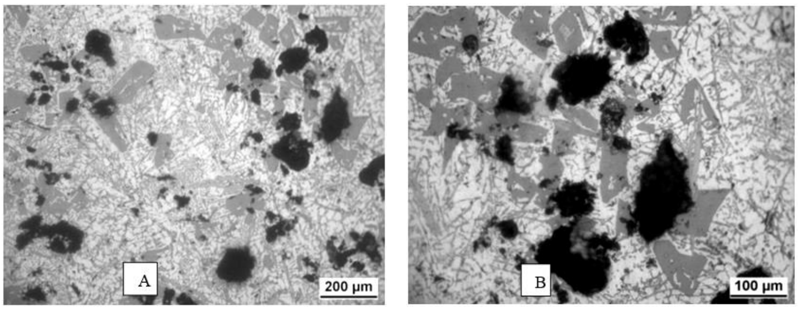
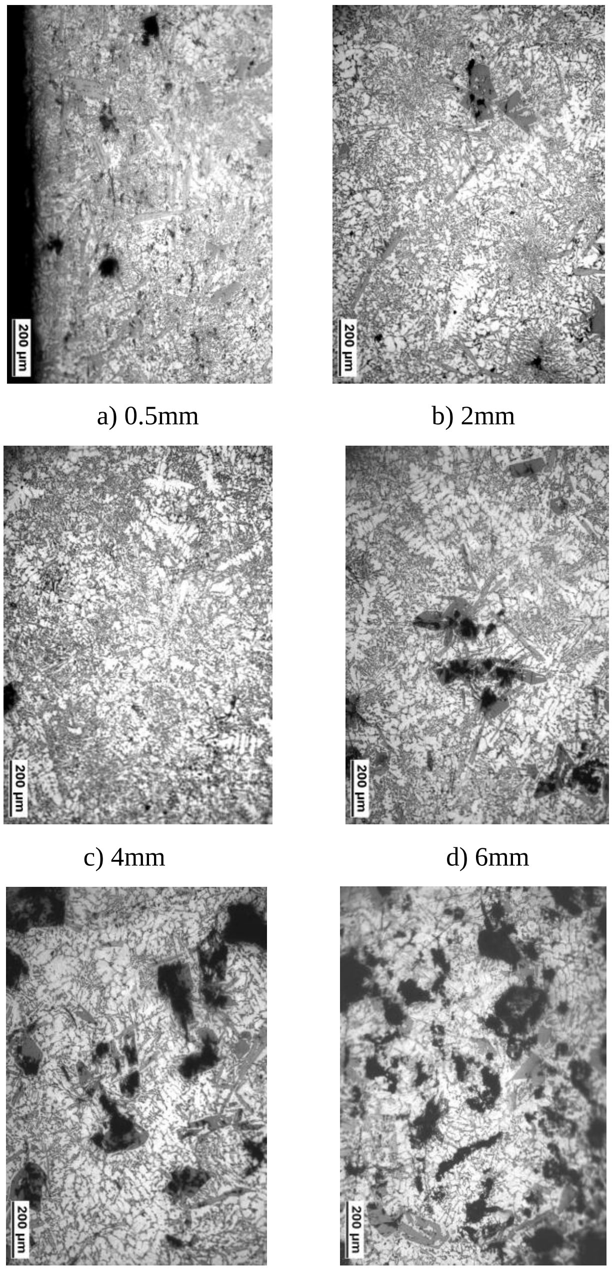


Figure 7. Microstructure of hybrid composite gravity casting (A, B)

Graphite accumulation has the low value due to the soft nature of graphite particles than the primary silicon region has the maximum hardness value. However the graphite addition enhances the solid lubrication property as well as the adhesive wear resistance of the component due to its property as a solid lubricant.

3.2. Composite produced by centrifugal casting

Figure 8 (a to f) shows the microstructure of hybrid FGCM LM30 Composite reinforced with graphite. The concentration of graphite is understood from outer periphery to inner periphery as in from figure 6. As the density of graphite (2 g/cc) is lower than aluminium (2.7 g/cc), it segregates towards the inner periphery with the primary silicon due to the action of centrifugal force. The addition of graphite in the matrix alloy refines the alpha aluminium and the eutectic silicon particles. As graphite is a solid lubricant, the adhesive wear resistance at the inner periphery should be higher than the outer periphery.



a) 0.5mm b) 2mm

c) 4mm d) 6mm

e) 8mm f) 10mm

Figure 8. Microstructure of hybrid FGCM by centrifugal casting. Captions show the distance from outer edge

Table 2 lists the hardness results of prepared centrifugal cast FGCM. The relation between hardness value and the distance from the outer surface of the centrifugal specimen is shown in grap (figure 9). From the figure, it is clearly inferred that the hardness toward the inner of the composite is decreasing due to the addition of graphite particles. The hardness of both LM30 alloy cast and LM30 alloy with 5 % wt graphite reinforced composite prepared by centrifugal cast were compared that is shown in figure 10. Result shows that the slight decrease in hardness at the inner edge. This is due to the high percentage of graphite present there (because graphite has low hardness compared to aluminium. But as graphite is a solid lubricant, the wear resistance at the inner periphery will be higher.

Table 2. Hardness value of centrifugal cast FGCM

Distance from outer surface (mm)	Hardness (BHN)
2	107
4	109
6	101
8	95
10	94

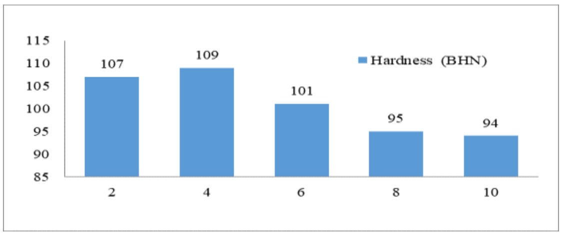


Figure 9. Relationship between hardness vs distance from outer surface in 'mm'

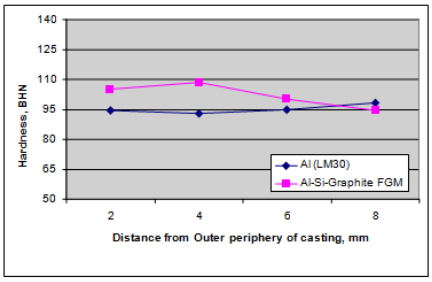


Figure 10. Hardness of LM30 alloy and LM30+5%wt graphite centrifugal cast

4. Conclusions

In gravity casting the particle distribution of Graphite and primary silicon were almost uniform. The addition of graphite refined the eutectic silicon particles and the alpha aluminum; but not the primary silicon. Graphite particle were mostly attached with primary silicon particles. The dendritic shape of primary aluminum was not observed in the case of composite, which is due to the hindrance given by the graphite particle during solidification as well as the stirring of the liquid metal during composite processing. The hardness value of gravity casting specimen was 125.3 BHN. The centrifugal casting showed the higher concentration of graphite towards the inner periphery so the hardness value was low at inner periphery. The adhesive wear resistance at the inner periphery was higher because graphite acted as a solid lubricant. In the case of primary silicon - graphite hybrid reinforced functionally graded composite, both the graphite and hybrid particles segregated towards the inner periphery due to their low density. The hard particle reinforcement by primary silicon could improve the strength and abrasive wear resistance and soft particle reinforcement by graphite could improve the adhesive wear resistance.

Reference

Chirita G., Soares D., Silva F. (2008). Advantages of the centrifugal casting technique for the production of structural components with Al–Si alloys. *Materials and Design*, Vol. 29, No. 1, pp. 20–27. http://doi.org/10.1016/j.matdes.2006.12.011

Duque N. B., Melgarejo Z. H., Suárez O. M. (2005). Functionally graded aluminum matrix composites produced by centrifugal casting. *Materials Characterization*, Vol. 55, No. 2, 167– 17. https://doi.org/10.1016/j.matchar.2005.04.005

Madhusudhan., Narendranaath S. S., Mohankumar G. C., Mukunda P. G. (2010). Effect of mould wall thickness on rate of solidification of centrifugal casting. *International Journal of Engineering Science and Technology*, Vol. 2, No. 11, pp. 6092-6096

Murugan S. S., Jegan V., Velmurugan M. (2018). Mechanical properties of SiC, Al_2O_3 reinforced aluminium 6061-T6 hybrid matrix composite. *J. Inst. Eng. India Ser. D*, Vol. 99, pp. 71-77. https://doi.org/10.1007/s40033-017-0142-3

Pradeep K. Rohatgi. (2008). Synthesis and Processing of Cast Metal-matrix Composites and Their Applications. *ASM Handbook*, Vol. 15, pp. 1149-1164. https://doi.org/10.1361/asmhba0005339

Rajan T. P. D., Pillai R. M., Pai B. C. (2003). Solidification processing of functionally gradient metals and metal-ceramic composites. *Indian Foundry Journal*, Vol. 49, No. 9, pp. 19-30

Saio C., Nocentini K., Tagliafico L. A., Biwole P. H., Achard P. (2017). Application of advanced insulating materials in historical buildings, *International Journal of Heat and Technology*, Vol. 35, No. 1, pp. S345-S352. https://doi.org/10.18280/ijht.35Sp0147

Subramanian S. M., Vijayan J., Muthaiah V. (2017). Tribological wear behaviour and hardness measurement of SiC, Al_2O_3 reinforced Al. *Matrix Hybrid Composite Journal of the Institution of Engineers (India): Series D*, Vol. 98, No. 2, pp. 291–296. https://doi.org/10.1007/s40033-016-0134-8

Wei S. F., Lampman S. (2008). Centrifugal casting. *ASM Handbook*, *Casting ASM Handbook Committee*, Vol. 15, pp. 667-673. https://doi.org/10.1361/asmhba0005257