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Fabrication of Aluminium Matrix Composite Using Thixoforming Process for High Strength Material Components

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Abstract: Aluminium-based MMCs (metal matrix composites) have many potential applications in the automotive manufacturing industry, aerospace and military because the aluminum has a low density. Aluminum as a matrix with Al_2O_3 reinforcement has attracted interest to be developed in order to improve the mechanical property. The study carried out the formation of Al-5%Cu-4%Mg matrix with the reinforcement of Al_2O_3 by thixoforming process. In this paper, we studied the effect of semisolid thixoforming process on strength of Al-5%Cu-4%Mg matrix. The matrix used here was doped by Al_2O_3 with the volume fraction from 5% to 20%. It is found that strength of MMCs significantly increases with increasing volume fraction of Al_2O_3 reinforcement from 5% to 20%. This is due to a good wettability in interface region such as formation of spinel $MgAl_2O_4$ phase. Moreover, toughness of MMCs increases by process of semisolid thixoforming due to evolution of microstructure such as globular and fine grain structures. These results indicate that the thixocasting process conducted in this study could increase the value of the matrix hardness and tensile strength, so that such process opens up opportunity for application in the manufacturing industry.

Key words: MMCs, Al-5%Cu-4%Mg, semisolid thixoforming, Al_2O_3 reinforcement, high strength material.

1. Introduction

Thixoforming-based aluminum alloys have been studied by several groups in order to improve the mechanical properties [1]. Most of semisolid thixoforming processes were reported on master alloy (Al-Cu). Wannasin [2] reported thixoforming process on Al-4.4%Cu with solid fraction of 50%. Jiang [3] investigated evolution of microstructure and mechanical property of Al-4Cu-Mg on semisolid process.

Moreover, research in master alloy with reinforcement (for example Al_2O_3 or SiC) has also attracted interest. Kok [4] investigated 2024 aluminum composite with reinforcement of 30% Al_2O_3. Onat [5] reported Al-4.5Cu-3Mg with 15 vf.% SiC. Their results showed that the mechanical properties are sensitively influenced by the reinforcement distribution, clustering and porosity. Thixoforming process has an advantage to reduce the problems of reinforcement distribution, clustering and porosity, so that the homogeneity of MMCs (metal matrix composite) microstructure could be obtained [6]. However, to our knowledge, only a few studies have been attempted on semisolid thixoforming of MMCs.

So far, we have reported the formation of Al-5%Cu-4%Mg matrix with the reinforcement of Al_2O_3 by thixoforming process [7]. In this work, we focus on the effect of semisolid thixoforming process on strength of Al-5%Cu-4%Mg matrix.

2. Experimental Setup

The materials used are pure Al ingot, Cu wire, Mg ingot as a matrix and alumina (Al_2O_3) as reinforcement. The chemical composition of Al, Cu and Mg before stirr casting process is 90.39 wt.%, 5.02 wt.% and 4.13 wt.%, respectively. The formation

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of master alloy of Al-5%Cu-4%Mg is as follows: first, Al ingot was melted at 700 °C in a muffle furnace, then Cu was introduced into the Al melted where Al and Cu were dissolved homogeneously, Mg ingot was inserted until the alloy dissolved. Finally, Al_2O_3 is poured into the master alloy matrix, then stirred with speed of 5,000 rpm for 30 s and flushed with argon gas. Afterward MMC has been formed then poured in the mold.

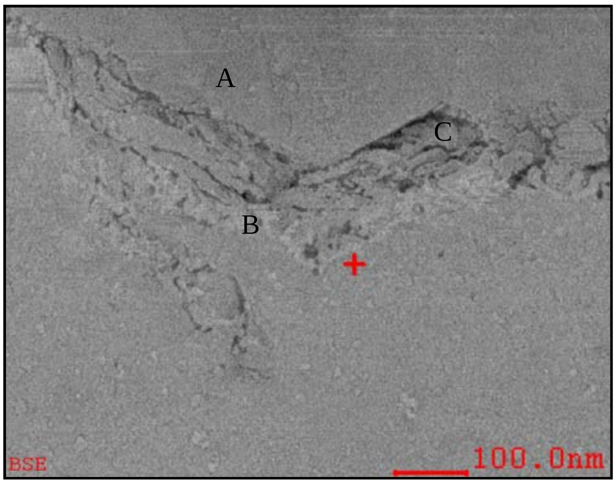
Thixoforming process was performed in open dies. Here, the temperature of the MMCs was increased to reach semi-solid temperature, and the composite was pressed by load pressure of 150 ton for 3 s.

The microstructure of MMCs was analysed by using optical microscope, while the hardness and tensile strength were measured by Frank Well Test and RMG 100-Germany, respectively.

3. Experimental Results

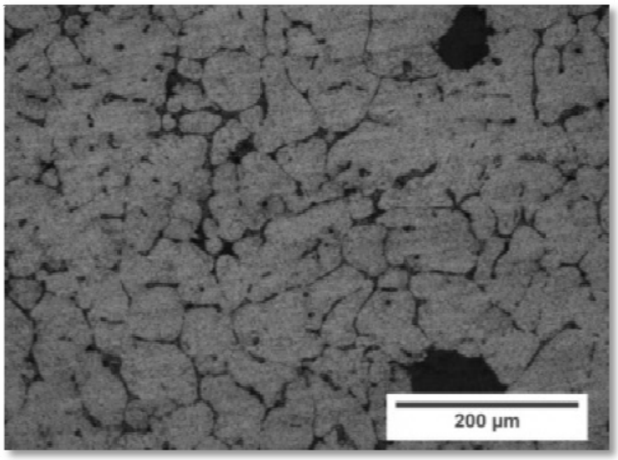
Mechanical properties of MMCs are influenced by volume fraction of reinforcement and morphology of microstructures of the matrix [8, 9]. Fig. 1 shows the optical microscope images of microstructure for MMCs with Al_2O_3 reinforcement of 5 vf.% (a), 10 vf.% (b), 15 vf.% (c), and 20 vf.% (d). It can be seen that, Al_2O_3 particles (black colour) are distributed on the AlCu microstructures surface. When the volume fraction of Al_2O_3 increases, Al_2O_3 particles are relatively distributed in large area on the whole of microstructures surface. It can be noted that the distribution of Al_2O_3 particles sensitively influences the mechanical properties (strength). We also found that the MMCs with Al_2O_3 reinforcement have a spinel $MgAl_2O_4$ phase that gives significance to good wettability in interface region (see Fig. 1) to increase the strength of MMCs [10]. Moreover, agglomeration (clustering) of Al_2O_3 particles is also found for higher volume fraction of Al_2O_3 (see Fig. 2d). Such agglomeration of Al_2O_3 particles could result in porosity, which tends to decrease the mechanical property [11]. We can see that, Al_2O_3 particles for sample of 15 vf.% (Fig. 2c) are homogenously distributed on the whole surface, indicating that MMCs with Al_2O_3 reinforcement of 15 vf.% are appropriate condition of Al_2O_3 volume fraction.

It is important to be noted that, thixoforming process results in the AlCu microstructure on the globular shape and fine, which is very essential for increasing the mechanical properties [12]. Such structures could be obtained by thixoforming process with appropriate parameters of pressure and temperature [13, 14].

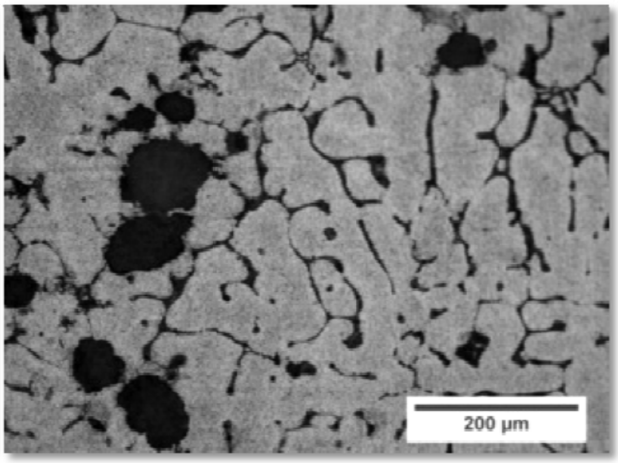


Location	Al (%)	Cu (%)	Mg (%)	O (%)
A	64.86	-	2.76	32.4
B	85.32	7.49	3.95	3.25
C	73.93	8.52	4.76	12.79

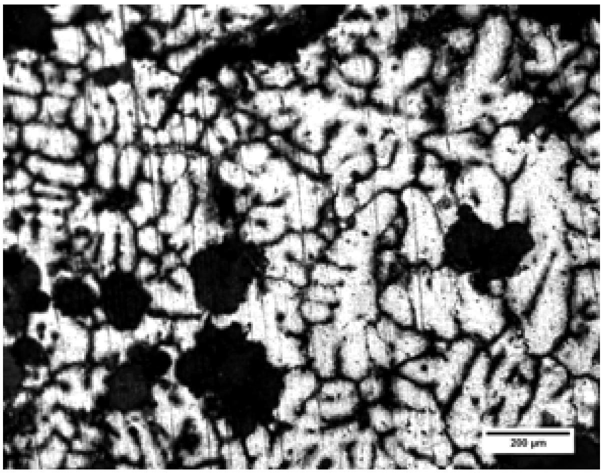
Fig. 1 SEM (scanning electron microscope)-EDS (energy dispersive spectrometer) examination at matrix area, interface, and reinforce.



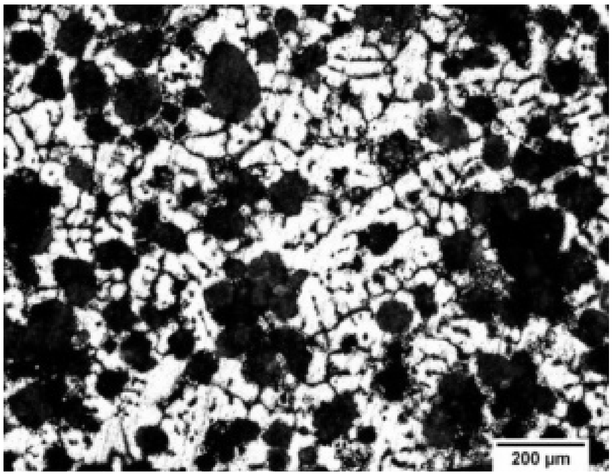
(a) MMCs with 5 vf.% Al_2O_3 reinforcement



(b) MMCs with 10 vf.% Al_2O_3 reinforcement

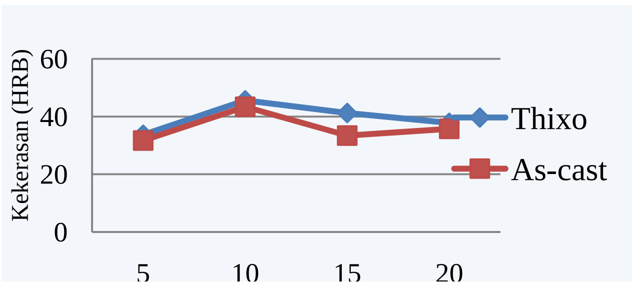


(c) MMCs with 15 vf.% Al_2O_3 reinforcement



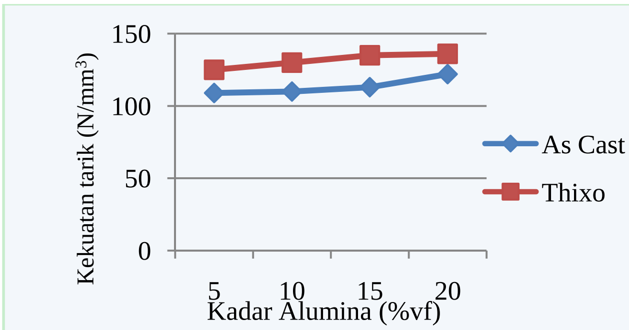
(d) MMCs with 20 vf.% Al_2O_3 reinforcement

Fig. 2 Optical microscope image of MMCs with Al_2O_3 reinforcement of (a) 5 vf.%, (b) 10 vf.%, (c) 15 vf.% and (d) 20 vf.%.



Al_2O_3 volume fraction (vf.%)

(a)



Al_2O_3 volume fraction (vf.%)

(b)

Fig. 3 Effect of semisolid thixoforming process on (a) hardness and (b) tensile strength of Al-5%Cu-4%Mg matrix.

Fig. 3a shows that semisolid thixoforming process successfully increases hardness of the matrix, compared to the initial condition (as-cast). When level of reinforcement Al_2O_3 was added from 5% to 20%, the hardness also increases from 34 HRB (for Al_2O_3 5%) to 37 HRB (for Al_2O_3 20%). As shown in Fig. 3b, semisolid thixoforming process also increases the tensile strength. The tensile strength increases from 121 N/mm^2 to 139 N/mm^2 when the Al_2O_3 was added from 5% to 20%.

4. Conclusions

We have studied the effect of semisolid thixoforming process on strength of Al-5%Cu-4%Mg matrix. The summary of the results is as follows.

(1) Strength of aluminum matrix composite significantly increases with increasing volume fraction of Al_2O_3 reinforcement from 5% to 20%. This may be caused by good wettability in interface region such as formation of spinel $MgAl_2O_4$ phase.

(2) Toughness of aluminum matrix composite increases by process of semisolid thixoforming due to evolution of microstructure such as globular and fine grain structures.

(3) Optimum strength and toughness can be obtained by semisolid thixoforming process on the condition of 15 vf.% SiC reinforcement.

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References

[1] Hirt, G., and Kopp, R. 2009. *Thixoforming-Semi-solid Metal Processing*. Weinheim: WILEY-VCH Verlag GmbH & Co. KGaA.

[2] Wannasin, J., and Thanabumrungkul, S. 2008. “Development of a Semi-solid Metal Processing Technique for Aluminium Casting Applications.” *Songklanakarin Journal of Science and Technology* 30: 215-20.

[3] Jiang, H., Lu, Y., Huang, W., Li, X., and Li, M. 2003. “Microstructural Evolution and Mechanical Properties of the Semisolid Al-4Cu-Mg Alloy.” *Journal of Material Characterization* 51: 1-10.

[4] Kok, M. 2005. “Production and Mechanical Properties of Al_2O_3 Particle-Reinforced 2024 Aluminium Alloy Composites.” *Journal of Material Processing Technology* 161: 381-7.

[5] Onat, A. 2010. “Mechanical and Dry Sliding Wear Properties of Silicon Carbide Particulate Reinforced Aluminium-Copper Alloy Matrix Composites Produced by Direct Squeeze Casting Method.” *Journal of Alloys and Compounds* 489: 119-24.

[6] Lu, Y., Li, M., Niu, Y., and Li, X. 2008. “Microstructure and Element Distribution during Partial Remelting of an Al-4Cu-Mg Alloy.” *Journal of Materials Engineering and Performance* 17: 25-9.

[7] Afandi, Y., Zulfia, A., Priadi, D., and Jujur, I. N. 2013. “Formation and Characterization of MMCs Alloy Al-5%Cu-4%Mg/SiC(p) by Thixoforming Process.” *Advanced Materials Research* 789: 56-9.

[8] Afandi, Y., and Adjiantoro, B. 2011. “Fabrication of MMCs Alloy Al-4.5%Cu-4%Mg/SiC(p) by Forging Process.” In *Proceeding of Quality in Research (QiR) 2011*, 1355-61.

[9] Kumar, G., and Sidedeshwara, P. 2017. “Microstructure and Mechanical Behaviour of *in Situ* faBricated AA6061-TiC Metal Matrix Composites.” *Science Direct* 535-4.

[10] Ashby, M. F., and Jones, D. R H. 1980. *Engineering Materials: An Introduction to their Properties and Applications*, edited by R. J. Brook. New York: Pergamon Press, 302.

[11] Bindumadhavan, P. N., Chia, T. K., Chandrasekaran, M., Wah, H. K., Lam, L. N., and Prabhakar, O. 2001. “Effect of Particle-Porosity on Tribological Behavior of Cast Aluminium Alloy A356-SiCp Metal Matrix Composite.” *Material Science and Engineering A* 315: 217-26.

[12] Liu, D., and Atkinson, H. V. 2003. “Microstructural Evolution and Tensile Mechanical Properties of Thixoformed High Performance Aluminium Alloys.” *Material Science and Engineering A* 361: 213-24.

[13] Ozedmir, I., Muecklich, S., Podlesak, H., and dan Wielage, B. 2011. “Thixoforming of AA 2017 Aluminium Alloy Composites.” *Journal of Materials Processing Technology* 211: 1260-7.

[14] Chen, Q. 2017. “Compound Forming of 7075 Aluminum Alloy Based on Functional Integration on Plastic Deformation and Thixoformation.” *Journal of Materials Processing Technology* 246: 167-75.