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Effect of Processing Parameters on Fabrication of Aluminum Matrix Composite (AMC) through Stir Casting Process

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ABSTRACT: Aluminum matrix composites (AMC) has been widely known to be used in a wide range of aircraft, automotive and industrial infrastructure applications, due to its mechanical and physical properties. In this work, AMC were fabricated through stir casting method with the Taguchi method to analysis significant contribution of parameter process in term of hardness property. For this purpose, the effects of various parameter processes pertaining during stir casting were performed have to be optimized. Aluminum alloy was used as a matrix with combination of various reinforced materials is fly ash, Silicon Carbide (SiC) and Alumina (Al_2O_3) with stirring speed (100, 200, and 300 rpm), stirring time (2, 4, and 6 min) and pouring temperature (700, 750 and 800 ºC). Results showed that composition was significant contribution percentage (41.97%) otherwise pouring temperature was minimum contribution (0.675%) to influence hardness.

KEYWORDS: Aluminium Matrix Composite; Stir casting; Hardness properties; Taguchi method.

INTRODUCTION

Rapid technological developments in areas such as aerospace, marine, civil and military which require the material ability to operate under extreme conditions lead to increased research on advanced materials [1, 2] . The utilize of metal matrix composite (MMC) in automotive industry has to be interested issue due to the beneficial properties of MMC such as light weight, high elastic modulus, improved strength, low coefficient of thermal expansion (CTE) and good wear resistance. Moreover, the issue of energy saving in the field of transportation is a classic issue; automotive companies have been trying to produce lighter vehicles to save fuel consumption [3-5]. To overcome this problem the automakers have tried to substitute some of the material components vehicles with the lightweight material such as aluminum alloys, magnesium alloys and metal matrix composites [6].

Single material is considered unable to meet the criteria required for vehicle components that have a critical function such as heavy load resistance, susceptible to friction and fatigue load [6]. The metal matrix composite has been proven to meet the required properties in a wide range of engineering applications [7]. Metal matrix composites (MMC) is a term combining single material usually used metal as matrix with reinforcement material while aluminum alloy as matrix with reinforcing material like SiC and alumina commonly referred to as aluminum matrix composites (AMC). Some studies have been done to produce MMC with some methods such as powder metallurgy and stir casting [8-11]

Stir casting or vortex technique have been widely utilized to fabricate aluminum matrix composite due to flexibility, simplicity, and applied to large volume fabrication. In stir casting, there are some of parameter process which influences final mechanical properties and microstructure of composite such as composition reinforced and matrix, stirring speed of blade, stirring time and melt temperature [12]. Moreover, nonhomogeneity of material reinforcement distribution in matrix and less wettability of material reinforcement is still an issue on stir casting technique [9].

Fly ash is the waste during combustion of coal at power plants which is the classic issue since coal firing for power generation was started [13]. Fly ash comprising to organic and inorganic components of feed coal that was generated at temperature 1200ºC - 1700ºC [14]. Fly ash is potentially hazardous waste due to its volatile toxic metal, the correct management of coal fly ash should be attention [15]. Mineralogical composition of fly ash comprising of mullite, ettringite, quartz, magnetite. Beside that fly ash has valuable oxide such as SiO_2, Al_2O_3, CaO and Fe_2O_3 content [15-17]. Composition and content of the fly ash produced can be different, it is influenced by the location of the coal and the combustion process performed [14, 18-20]. Generally, coal is divided into four types: anthracite, bituminous, sub-bituminous, and lignite. Chemical composition of fly ash from different coal type as shown in the Table 1.

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Table 1. Chemical composition of fly ash from different coal type [19].

Component (wt.%)	Bituminous	Sub-bituminous	Lignite
SiO_2	20–60	40–60	15–45
Al_2O_3	5–35	20–30	10–25
e_2O_3	10–40	4–10	4–15
CaO	1–12	5–30	15–40
MgO	0–5	1–6	3–10
SO_3	0–4	0–2	0–10
Na_2O	0–4	0–2	0–6
K_2O	0–3	0–4	0–4
LOI	0–15	0–3	0–5

The objective of the study is to determine which factors contribute to hardness properties of AMC. The effect of four stirs casting process: composition, stirring speed, stirring time and melt temperature on the final hardness property were investigated the optimum sintering condition was proposed. To analyses feasibility of fly ash as reinforce material; two types of common material reinforced SiC and Al_2O_3 are utilized as comparison.

EXPERIMENTAL PROCEDURE

Fabrication of AMC was prepared by Stir casting technique involving aluminum alloys as matrix in low carbon steel crucible. Fly ash powder was obtained from Tanjung Enim power plant was located in South Sumatra, Indonesia. Fly ash powder was preheated to 600°C for 1 hour to remove moisture before mixing it with the aluminum melt. Table 2 shows the composition of Aluminum alloy. SiC powder was supplied by Ujiden Chemical Industry, Co. Ltd. Japan.

Table 2. Chemical composition of aluminum alloy.

Elements	Al	Mn	Fe	Cu	Zn	Sn	Pb	Others
Wt%	97.48	0.676	0.502	0.756	0.498	0.013	0.067	Bal.

Fly ash 12 wt %, Silicon Carbide (SiC) 12 wt % and Alumina (Al_2O_3) 12 wt% were added into aluminum melt on pouring temperature. Vortex flow was created using rotating mixing blade which generated by an electric motor with speed control panel to adjust mixing blade speed. Some author reported that wettability and reactivity has play important role to determine of quality bonding between reinforce material and matrix which influence of final of mechanical properties of composite [21, 22]. Magnesium (2.5 wt %) was added to improve the wettability and integration fraction of reinforce particle. Addition of magnesium as wettability agent is expected to reduce aluminum oxide by binding oxygen content. Molten aluminum alloy with reinforced material was poured into a permanent mold by gravity casting method.

In this work, significant parameters contribution for hardness on stir casting was analyzed using Taguchi method with L9 orthogonal array. The experimental layout of this work is four parameters and three levels as shown on Table 3.

Table 3. Experimental layout and factors distribution of orthogonal array (L_9).

No.	Factors				Experimental Value			
	A	B	C	D	Composition	Stirring speed	Stirring time	Pouring temperature
1	1	1	1	1	Al+ *fly ash* 12 wt%	100 rpm	2 min	700 °C
2	1	2	2	2	Al+ *fly ash* 12 wt%	200 rpm	4 min	750 °C
3	1	3	3	3	Al+ *fly ash* 12 wt%	300 rpm	6 min	800 °C
4	2	1	2	3	Al+ SiC 12 wt%	100 rpm	4 min	800 °C
5	2	2	3	1	Al+ SiC 12 wt%	200 rpm	6 min	700 °C
6	2	3	1	2	Al+ SiC 12 wt%	300 rpm	2 min	750 °C
7	3	1	3	2	Al+ 12 wt%	100 rpm	6 min	750 °C
8	3	2	1	3	Al+ 12 wt%	200 rpm	2 min	800 °C
9	3	3	2	1	Al+ 12 wt%	300 rpm	4 min	700 °C

The objective of this work is to determine the effects of stir casting factors on the final hardness and the optimum set of factors that would maximize the final hardness.

RESULTS AND DISCUSSION

The hardness of aluminum matrix composite (AMC) via stir casting process was measured by the Brinnel method with steel ball as an indenter. Brinell method was utilized due to aluminum matrix composite is no homogeneous due to the existence of the added reinforcing material. Figure 1 shows the results of five traces of hardness testing using a steel ball indenter.

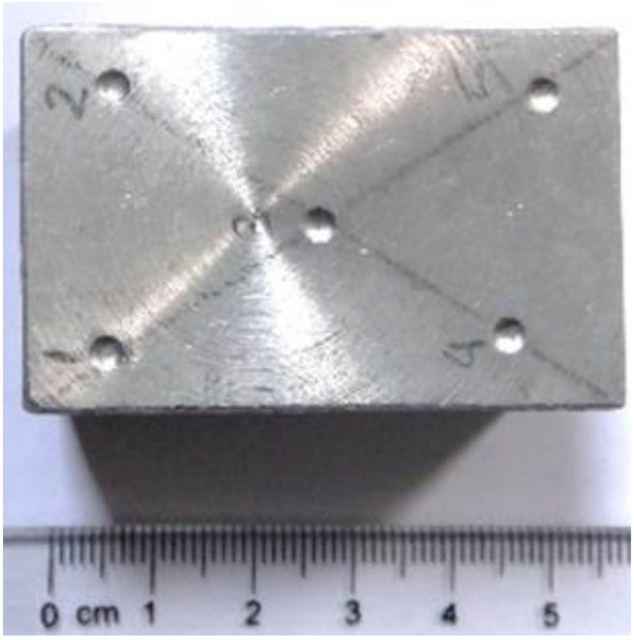

Figure 1. Specimen for hardness measurement.

Four readings (corresponding to the theree replications) were recorded for each experimental condition as shown in Table 4. The analysis of variance (ANOVA) procedure was used to establish the relative significance of the factors. ANOVA is an information table showing the relative influence of factors and interactions assigned to orthogonal array columns. Table 5 shows the results of the ANOVA after "pooling" with ''at least 99% confidence'' for hardness result of aluminum matrix composite.

Tabel 4. Hardness result of aluminum matrix composite.

No.	Experimental condition and hardness value					
	Composition	*v* (rpm)	*t* (min)	*T* (°C)	$\overline{BHN}$ (Kgf/mm^2)	*S/N ratio* (dB)
1	Al+Mg 2 wt%+*fly ash* 12 wt%	100	2	700	64,25	32,38
2	Al+Mg 2 wt%+*fly ash* 12 wt%	200	4	750	70,91	33,40
3	Al+Mg 2 wt%+*fly ash* 12 wt%	300	6	800	73,24	33,54
4	Al+Mg 2 wt%+ SiC 12 wt%	100	4	800	73,27	33,59
5	Al+Mg 2 wt%+ SiC 12 wt%	200	6	700	83,59	34,82
6	Al+Mg 2 wt%+ SiC 12 wt%	300	2	750	78,74	34,32
7	Al+Mg 2 wt%+ Al_2O_3 12 wt%	100	6	750	76,20	33,95
8	Al+Mg 2 wt%+ Al_2O_3 12 wt%	200	2	800	75,49	33,92
9	Al+Mg 2 wt%+ Al_2O_3 12 wt%	300	4	700	82,00	34,63

Table 5. ANOVA for hardness of aluminum matrix composite

Source	Pool	SS	DF	MS	F Ratio	SS`	Ratio (%)	F Tabel
A	Y	461,232	2	230,616	19,416	437,477	41,979	3,56
B	Y	230,394	2	115,197	9,699	206,639	19,828	3,56
C	Y	105,922	2	52,961	4,459	82,167	7,884	3,56
D	Y	30,789						
Error		213,794						
Pooleed		244,583	20	12,229	1	315,848	30,308	
SS_t		1042,132	26	426,046		1042,132	100	
Mean		153.084,9	1					
SS_{total}		154.127	27					

From the ANOVA table, the effects of stir casting factors on the final hardness were determined. All the four stir casting factors have significant contribution on the hardness at the 99% significance level as showed

Figure 2. Comparing with the other three stir casting factors, the composition yield the most significant contribution (41,979 %), on hardness as shown by the much higher F ratio. The second parameter that gives a second major influence on the value of hardness is stirring speed (B). Stirring speed plays an important role in determining the distribution of reinforcing materials. Accumulation of a reinforcing material will occur on low stirring speed which can result in a non-uniform hardness value of composite. Moreover combination of higher stirring speed and stirring time have strong effect to increase hardness of composite [23].

In this case, pouring temperature (D) does not have a significant contribution on hardness however it is impossible to remove pouring temperature factor from stir casting parameters.

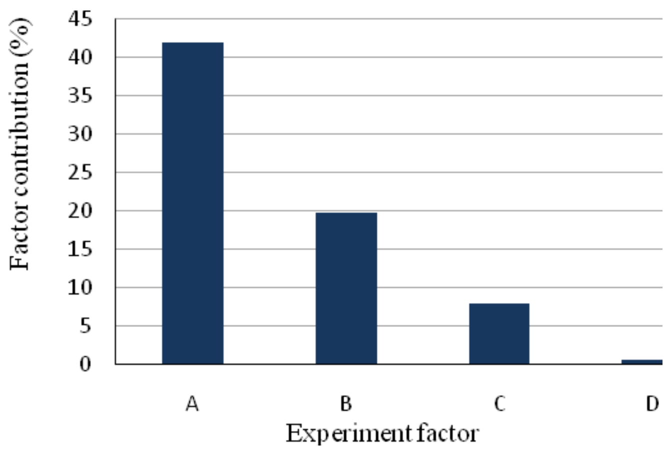

Figure 2 Factor contribution on hardness value of aluminum matrix composite.

Figure 3 shows response of hardness value for aluminum matrix composite with various level. Composition (A) is the most significant contribution properties otherwise the pouring temperature (D) does not have a significant effect for hardness properties. SiC has significant contribution to increase hardness properties of aluminum matrix composite compare to fly ash and Al_2O_3. Moreover, composition of silicon carbide in level 2 has significant contribution in hardness value Brinnel.

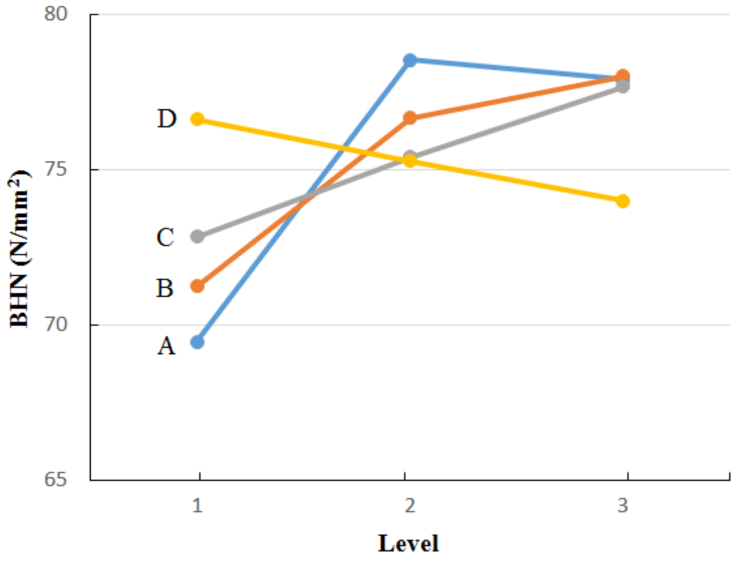

Figure 3. Response graphs of hardness value against various factors.

Based on ANOVA calculation the significant effect for stir casting was calculated. According to optimum condition "Larger the better" the highest average value contribution is consider optimum condition. Regarding hardness properties response for the optimum parameter was obtained on condition; composition, stirring speed, stirring time and pouring temperature is Al+ SiC 12 wt%, 300 rpm,6 min and 700ºC, respectively.

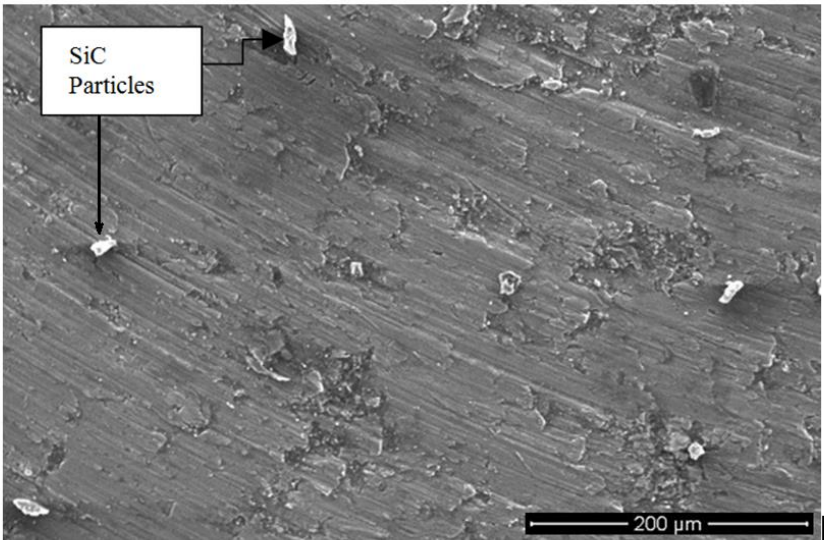

Figure 4. SEM images showing the microstructure of aluminum matrix composite.

Figure 4 shows microstructure of aluminum matrix composite where distribution of particles as reinforced material was observed on the morphology of composite. Regarding of homogeneity particles is classic issue in manufacturing metal matrix composite using stir casting method. Speed of blade and stirring time parameters are playing important role in stir casting process. At lower stirring speed hardness value tend to not uniform, maximum hardness value is obtained where the reinforcing particle accumulation is more [23].

In this work, maximum hardness value was obtained on composite with SiC particle. SiC has play important role to increase hardness properties of the cast aluminum composite [24, 25]. The addition of SiC powder to the aluminum alloy as a matrix can influence the value of composite hardness. This is because aluminum is a soft material and SiC has a high hardness value so as to contribute positively to composite hardness. In addition, strong and rigid SiC particles play an important role in increasing the plastic deformation resistance of the matrix during the hardness test [26]. Some authors report that the Aluminum carbide phase (Al_4C_3) is formed when SiC is mixed with liquid aluminum [27, 28]. In term of aluminum matrix composite with SiC as reinforced, Al_4C_3 formation in the interphase is brittle phase. This phase formation will be detrimental and should be avoided as it will decrease mechanical properties [29].

CONCLUSIONS

Aluminum matrix composite with fly ash, SiC and Al_2O_3 as reinforced materials were successfully fabricated using stir casting method. Optimization process for fabrication aluminum matrix composite with hardness as response has been conducted using Taguchi method. Optimum parameter was obtained on parameter conditions (Al+ SiC 12 wt%, 300 rpm, 6 min and 700ºC). Composition parameter is the most significant contribution for hardness. Moreover, compare to fly ash and Al_2O_3 as reinforced, SiC has significant contribution to increase hardness properties. On the other hand, the pouring temperature is the least significant parameter for hardness.

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