Optimization of Stir Casting Method of Aluminum Matrix Composite (AMC) for the Hardness Properties by Using Taguchi Method

(Pengoptimuman Kaedah Tuangan Kacau Komposit Matriks Aluminium (AMC) bagi Sifat Kekerasan Menggunakan Kaedah Taguchi)

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ABSTRACT

Aluminum matrix composite (AMC) was fabricated using stir casting with fly ash and SiC as reinforcing materials. In this work, Taguchi optimization technique was utilized to analyze the significant contributions of stir casting parameters on the hardness properties of AMC. For this reason, stir casting was carried out by utilizing the combination of process parameters based on three-level of L9 Taguchi. The signal-to-noise (S/N) and the analysis of variance (ANOVA) were used to find the optimum levels and to indicate the impact of the process parameters on the hardness properties. The results show that some of process parameters have significant effect on the hardness, by comparing with the other three sintering factors, the composition of reinforcement materials gave the most significant effect on the hardness.

Keywords: Taguchi method; Stir casting; Fly ash; Aluminum matrix composite

INTRODUCTION

Reducing weight and cost are some of main issues in the automotive industry. Intensive efforts have been conducted by the automakers to reduce the car weight. Meanwhile the consumers demand for improved safety, interior comfort, navigation and entertainments (Macke, Schultz & Rohatgi 2012). To answer these challenges automotive manufacturers of automotive are turning to light-weight metals as solution. Light-metal such as aluminum (Al) is the exact choice to replace steel in automotive components due to its low density compared to steel. Alternator housings, transmission housings, valve covers, and intake manifolds are the potential automotive components to that can be replaced with Al. Although Al is capable in reducing the weight of automotive components mechanical properties of aluminum such as hardness, strength and impact properties should be improved. Several studies have been performed to meet these challenges in terms of the processing route, design and material modification (Krishna & Xavior 2014; Latif, Sajuri & Syarif 2014; Sun, Lyu, Jiang & Zhao 2014; Vogiatzis, Tsouknidas, Kountouras & Skolianos 2015).

Fabrication of aluminum matrix composite (AMC) using stir casting with additional reinforcing material is a method to increase the mechanical properties. Many researchers have added ceramic particles to increase the mechanical properties of aluminum such as SiC, Alumina, TiC and Graphite (Alaneme & Sanusi 2015; Dehghan Hamedan & Shahmiri, 2012; Ghazali 2006; Krishna & Xavior 2014; Moses, Dinaharan & Sekhar 2016; Sharma, Sharma & Khanduja 2015; Silva, Stainer, Al-Qureshi, Montedo & D.Hotza 2014). SiC is a non-oxide ceramic material that was used for the fabrication of AMC (Rosso 2006). Some authors have also added SiC into the fabrication of AMC as reinforcement material (Inegbenebor, Bolu, Babalola, Inegbenebor & Fayomi 2016; Rana, Purohit, Soni & Das 2015). Mechanical properties of AMC such as tensile, compressive and hardness tend to improve the weight percentage of SiC particles in AMC increased (Moses, Dinaharan & Sekhar, 2014; Rana et al. 2015).

Issues of fly ash waste and high cost of reinforcement materials result to the main idea of combining fly ash and common reinforcement materials such as SiC and Al_2O_3. By mixing aluminum alloy with fly ash using stir casting, high dislocation density of such composites can be created and enhance their mechanical properties (Anilkumar, Hebbar & Ravishankar 2011). Anilkumar et al. (2011) also reported that smaller size of fly ash weakens hardness, tensile and compressive strength the composite. Investigations on the mechanical and physical properties of AMC that involve fly ash mixed with various common reinforcement materials have also reported (Alaneme & Sanusi 2015; Krishnaraj, Divinesh & Mohaideen 2016; Kumar, Srinivas, Ramachandra, Mahendra & Nagara 2015; Lin, Li, Hou & Li 2015; Visa, Andronic & Duta 2015). The addition of SiC into aluminum – fly ash composite plays an important role in increasing micro and macrohardness (David Raja Selvam, Robinson Smart & Dinaharan 2013). It was found that the increasing weight proportion of SiC increased the micro and macrohardness of such composite. The same trend was also reported where the hardness and tensile stress are improved as the SiC and fly ash contents increased (Krishnaraj et al. 2016). In this work, a hybrid composite of Al (SiC+Fly ash) was prepared, and the microstructure analysis and the optimization of mechanical properties by using Taguchi method, for such composite were presented.

METHODOLOGY

In this work, alumunium alloy is a Al-Si type, while SiC and fly ash are the reinforcement materials. Al-Si alloys was melted in a steel crucible at 700°C furthermore. The SiC and fly ash were than added. During this melting process, stirring was added by a steel blade which generated by an electric motor.

Aluminum matrix composite fabrication via stir casting involves many process parameters such as mold, composition and furnace. Figure 1 shows the parameters from each parts (mould, furnace, matrix alloy and stirrer) that may influence the hardness of AMC during the stir casting process is performed.

Composition of AMC, stirring speed, stirring time and molten temperature were selected according to Taguchi experimental design methodology where each of the parameters have three levels as shown in the Table 1. Figure 2 shows stir casting process that has been done to melt the AMC using alumunium alloys, mixing blade that is generated by the electric motor with controllable speed.

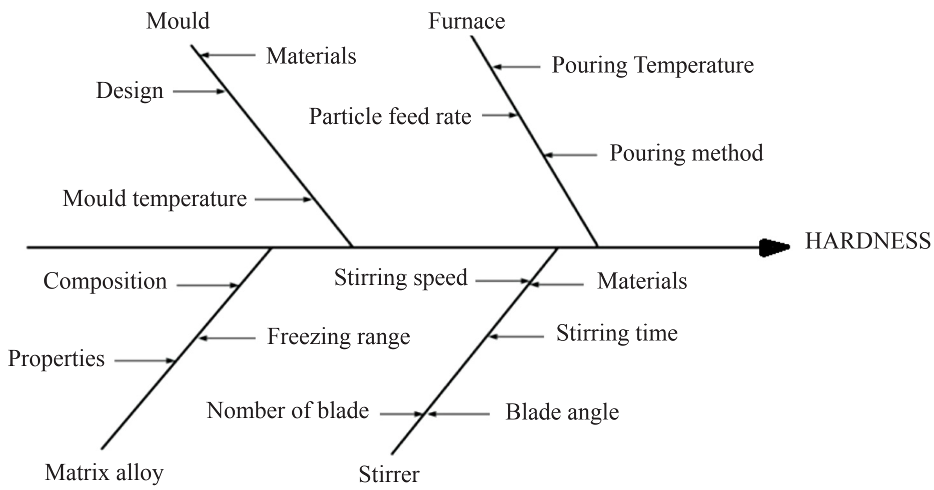

FIGURE 1. Influence of various parameters in stir casting process on the hardness of AMC

TABLE 1. Process parameters and their respective factors and levels for stir casting process

Factor	Level		
	1	2	3
Composition of AMC (A)	Al+SiC8wt%+*Fa*4wt%	Al+SiC8wt%+*Fa*8wt%	Al+SiC8wt%+*Fa*12wt%
Stirring speed (B) (rpm)	300	350	400
Stirring time (C) (min)	3	5	7
Molten temperature of AMC (D) (°C)	700	750	800

RESULTS AND DISCUSSION

Figure 3 shows the hardness values of AMC based on Brinell Hardness Number (BHN) with a steel ball as the indenter. Meanwhile, Table 3 shows the reading for each experimental condition. ANOVA was utilized to identify the factors that contribute significantly to the hardness of AMC. Table 4 shows the hardness average and S/N ratio. To achieve the optimum hardness value of AMC, “Larger the better” was utilized.

Figure 4 shows a response graph of mean hardness for each factors. An optimum conditon of hardness value was achieved based on the conditions of; A3, B2, C3 and D3, respectively. It was found that the hardness increased proportionally as the level increased in Factor A.

Based on ANOVA results as shown in Table 5. it is known that Factor A and Factor B improve the hardness. Factor C and Factor D gave less effect on the hardness of AMC. However, Factor D is an important source and can not be eliminated during the manufacturing process of AMC.

Table 5 also shows that the contribution error of 8.49% was obtained where such percentage means that all significant factors affect the average value; therefore, it is enough to be involved in the experiment. This is due to the requirement by Taguchi method that the message contribution must be ≤ 50%.

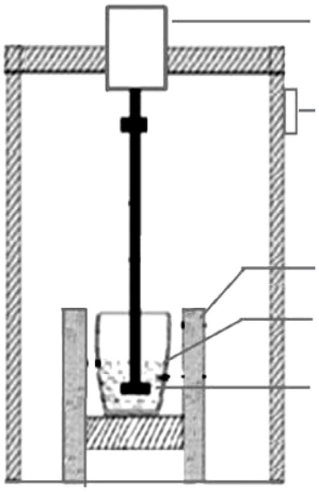

FIGURE 2. Schematic of stir casting process

ANOVA also indicates that Factors A and Factor B have significant contribution on the hardness as shown in Table 5. The expected average of optimum condition could be determined by Equation (1).

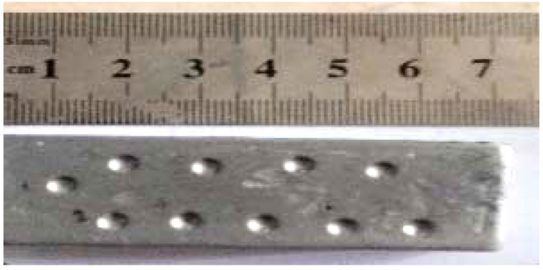

FIGURE 3. Specimens for hardness test

$$\text{Hardness}_{\text{expected result at optimum condition}} = \overline{A3} + \overline{E2} - \bar{y} \quad \text{.....(1)}$$

$$\text{BHN}_{\text{expected result at optimum condition}} = 57.34 + 53.95 - 52.0326$$

$$\text{BHN}_{\text{expected result at optimum condition}} = 59.2574 \text{ Kgf/mm}^2$$

The 90% confidence interval (Cl_{mean}) for the expected yield from the verification experiment can be determined by Equation (2) as

TABLE 2. Experimental layout and factors distribution of L9 OA

No.	Factor				Experimental Value			
	A	B	C	D	Composition of AMC (A)	Stirring speed (rpm) (B)	Stirring time (min) (C)	Molten Temperature of AMC (°C) (D)
1	1	1	1	1	Al+SiC8wt%+*Fa*4wt%	300	3	700
2	1	2	2	2	Al+SiC8wt%+*Fa*4wt%	350	5	750
3	1	3	3	3	Al+SiC8wt%+*Fa*4wt%	400	7	800
4	2	1	3	3	Al+SiC8wt%+*Fa*8wt%	300	5	800
5	2	2	2	1	Al+SiC8wt%+*Fa*8wt%	350	7	700
6	2	3	1	2	Al+SiC8wt%+*Fa*8wt%	400	3	750
7	3	1	3	2	Al+SiC8wt%+*Fa*12wt%	300	7	750
8	3	2	1	3	Al+SiC8wt%+*Fa*12wt%	350	3	800
9	3	3	2	1	Al+SiC8wt%+*Fa*12wt%	400	5	700

TABLE 3. Hardness values for all specimens

No	Factor				Replications		
	Fv (wt%)	V (rpm)	T (minute)	T (°C)	BHN	BHN	BHN
1	Al+SiC8+*Fa*4	300	3	700	47.09	46.44	46.77
2	Al+SiC8+*Fa*4	350	5	750	45.81	48.42	47.75
3	Al+SiC8+*Fa*4	400	7	800	45.81	47.75	47.09
4	Al+SiC8+*Fa*8	300	5	800	47.75	49.10	49.79
5	Al+SiC8+*Fa*8	350	7	700	53.44	51.94	53.50
6	Al+SiC8+*Fa*8	400	3	750	53.83	51.94	54.60
7	Al+SiC8+*Fa*12	300	7	750	54.60	55.00	53.44
8	Al+SiC8+*Fa*12	350	3	800	61.82	59.14	63.39
9	Al+SiC8+*Fa*12	400	5	700	55.00	59.14	54.21

TABLE 4. Hardness and S/N response values

No. Experiment	Factor				(BHN)	S/N Ratio
	A	B	C	D		
1	1	1	1	1	46.77	29.95
2	1	2	2	2	47.33	30.18
3	1	3	3	3	46.89	30.07
4	2	1	2	3	48.88	30.43
5	2	2	3	1	52.96	31.02
6	2	3	1	2	53.46	31.11
7	3	1	3	2	54.35	31.26
8	3	2	1	3	61.55	32.33
9	3	3	2	1	56.12	31.60

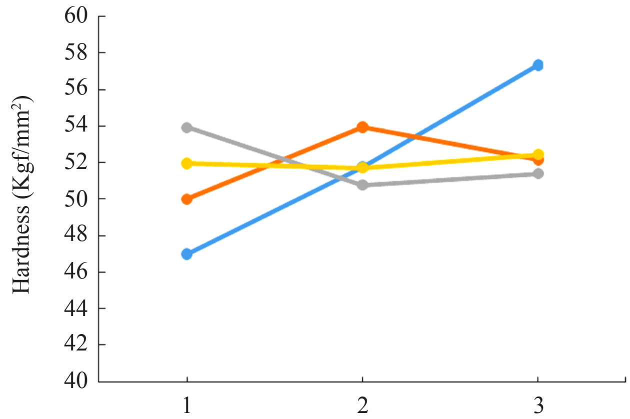

FIGURE 4. Response graphs of mean hardness at various factors and levels

TABLE 5. ANOVA result for aluminum matrix composite hardness

Source	Pooled	SS	DF	MS	F Ratio	SS'	Ratio (%)	F Table
A		482.49	2	241.24	111.03	478.14	74.19	3.56
B		70.29	2	35.14	16.17	65.94	10.23	3.56
C		50.06	2	25.03	11.52	45.71	7.09	3.56
D	Y	2.50						
Error	Y	39.11						
Pooleed		41.61	20	2.0805	1	54.61	8.49	
SSt		644.45	26	304.80		644.4	100	
Mean		73100	1					
SS_{total}		73744	27					

$$Cl_{mean} = \pm\sqrt{F_{a,v1,v2}\cdot MS_e\cdot\left(\frac{1}{neff}\right)} \quad ......(2)$$

$$Neff = \frac{\text{Total number of experiments}}{1 + Number\ of\ DOF}$$

$$neff = \frac{2f}{1+2+2}$$

$$neff = 5.4$$

$$Cl_{mean} = \pm\sqrt{F_{a,v1,v2}\cdot MSe\cdot\left(\frac{1}{neff}\right)}$$

$$Cl_{mean} = \pm\sqrt{F_{0.05,1.26}\cdot(2{,}173)\cdot\left(\frac{1}{5.4}\right)}$$

$$Cl_{mean} = \pm\sqrt{4.23\cdot(2{,}173)\cdot\left(\frac{1}{5.4}\right)}$$

$$Cl_{mean} = \pm 1.30$$

The confidence interval for the optimum mean surface hardness value is: 59.257 ± 1.30 kgf/mm^2, which equivalent to = 57.957 to 60.557 kgf/mm^2.

From the analysis of experimental result using Taguchi method, the addition of fly ash plays an important role to the hardness of AMC. The maximum hardness was given by the biggest weight percentage of fly ash composition. The second factor that contributes the highest value of hardness is the stirring speed of 350 rpm. It was found that the hardness deteriorated as the stirring speed increase than 350 rpm. It is believed that porosity was formed in the AMC due to the stirring blade as the speed increased.

CONCLUSIONS

Fabrication of AMC using the stir casting was succesfully conducted. The hardness of AMC was optimised by Taguchi method. ANOVA showed that two stir casting factors which are composition and stirring speed affect the AMC hardness significantly. The optimal level was found at A3 and B2. Based on ANOVA, the composition of AMC (Factor A) and stirring speed (Factor B) influence the hardness significantly by 74.19% and 10.23%, respectively. Meanwhile, the molten temperature of AMC (Factor D) gave no significant effect on the hardness of AMC.

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