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Analysis of Aluminium Basalt Particulate Composite Using Stirring Casting Method Through Taguchi Method Approach

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Abstract. Aluminium matrix composites (AMCs) becomes a choice for automotive and aerospace industries due to its tenable mechanical properties such as high hardness and good strength to weight ratio. Reinforcement like particulate alumina, silicon carbide, graphite, fly ash, etc can easily be incorporated in the melt using cheap and widely available stirring casting method. This research investigates the optimum hardness of AMCs containing basalt powder as reinforcement by setting varying parameter. The design of experiments (DOE) approach using Taguchi method orthogonal arrays L9 (3^3) factors 3 runs 9, was employed to predict the hardness of material casting with variable parameters such as matrix composition, stirring time, and particle size (mesh) of basalt. ANOVA and S/N ratio for determining optimum hardness (HRb) material and P-value confirms most significant parameter that affects the hardness at optimum level parameters to improve the mechanical properties of AMCs. Analysed Taguchi design observed that particle size (mesh) of basalt has a significant contribution on hardness (72.71%) followed by concentration of basalt (18.62%) and stirring time (8.45%) with an error about 0.22%. Based from previous study and field experiment, this result is match especially from different particle size will affect most of mechanical properties of composite materials.

1. Introduction

In this few past years, the global needs for low cost, high performance and good quality materials had turn the interest of research from the uses of monolithic materials to composite materials. Composite is a material that are made from two or more mixture of materials. In other words, it is a combination of two or more nano, micro or macro constituents with an interface separating them that vary in form and chemical composition and they are essentially insoluble for each other [1]. In case of metal matrix composites (MMCs), aluminium matrix due to their high strength to weight ratio, low cost and high wear resistance are widely manufactured and use in structural applications along with aerospace and automotive industry [2]. AMCs can be classified into four types depending on the type of reinforcements which are the particle reinforce AMCs (PAMCs), the whisker or short fibre-reinforced AMCs (SFAMCs) the continuous fibre reinforced (CFAMCs) and the monofilament reinforced AMCs (MFAMCs) [1-2].

AMCs has a lower density, wear resistance, high strength, and high elasticity so that mechanical properties which are desired can be determined depends on a combination of the matrix, reinforcement, and interface. Those properties of AMCs are the main attention for the researcher to make AMCs as a substitute for the current conventional materials [3]. It was found that most of the researches do studies about AMCs that used the aluminium composite with a particle as reinforcement [4], but seldom found the uses of recycle aluminium waste as the matrix in AMCs. Recycle aluminium waste to make AMCs became an interest due to the performance, economic and environmental benefits. Even in the country of United States of America (USA), the production of aluminium is also yield from the recycling process [5]. In Lampung, Indonesia, the aluminium waste such as dross are occasionally found to be recycled as the waste are observed littered in the surrounding environment. Aluminium waste still possesses the characteristic of the normal aluminium, but with a higher aluminium oxide content due to the aluminium melting process. When this material is used as a matrix component in the composite material, it could produce a mix characteristic that would overcome the weakness of each of the material used as raw composite. With the used of aluminium waste as component in the composite material, it could eventually solve the environmental problems as well as added a higher value to the aluminium waste.

2. Modelling of design research

2.1. Stir casting

In the stir casting process, usually, the particulate reinforcement is distributed into the molten aluminium by mechanical stirrer. The important parameters in the process of stir casting determine by the physical or mechanical properties. The parameters are the temperature of casting, the stirring time and the velocity of stirring [6]. Based on Raja et al. [7], the study uses basalt particle in order to increase the hardness of the material and resistance of wear where the value is directly proportional to the percentage of basalt as the reinforcement. In this research, there are three levels selected for three parameters, the percentage of weighing basalt particle, the stirring time, and the particle size (mesh) of basalt.

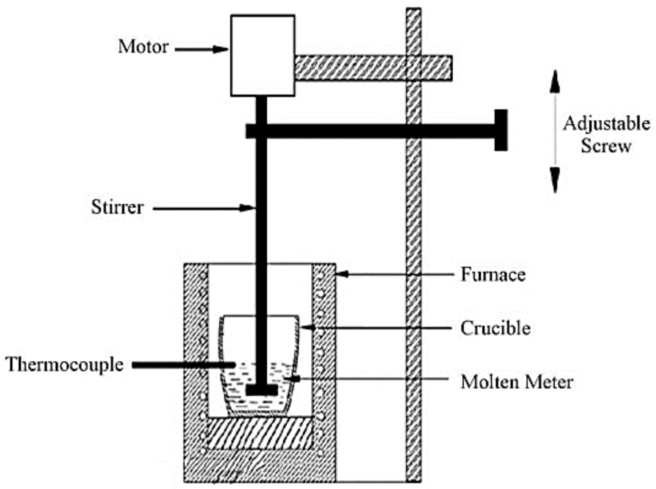

Figure 1. Schematic diagram of stirring casting process [4]

2.2. Taguchi Method

Taguchi design is the most powerful approach in order to achieve a high quality of work at a reduced cost. It is the statistical analysis tool by Dr Taguchi that was introduced which is focused on three concepts adequate to achieve the desired quality of products; system design parameters, and tolerance

[8]. The selection of materials and methods for the experimentation according to Taguchi method L9 orthogonal array selected for three levels of three parameters, are shown in Table 1.

Table 1. Taguchi orthogonal array design used L9 (3^3) factors 3 runs 9

Factors	Level 1	Level 2	Level 3
% w/t Basalt	5	10	15
Stirring time (minutes)	5	10	15
Particle size (mesh)	100	200	325

Table 2. Level and factor in stir casting

Sample No.	Basalt (%)	Stirring time (minutes)	Particle size (mesh)
1	5	5	100
2	5	10	200
3	5	15	325
4	10	5	200
5	10	10	325
6	10	15	100
7	15	5	325
8	15	10	100
9	15	15	200

For experimental procedure, the total of nine samples runs are taken as shown in Figure 2.

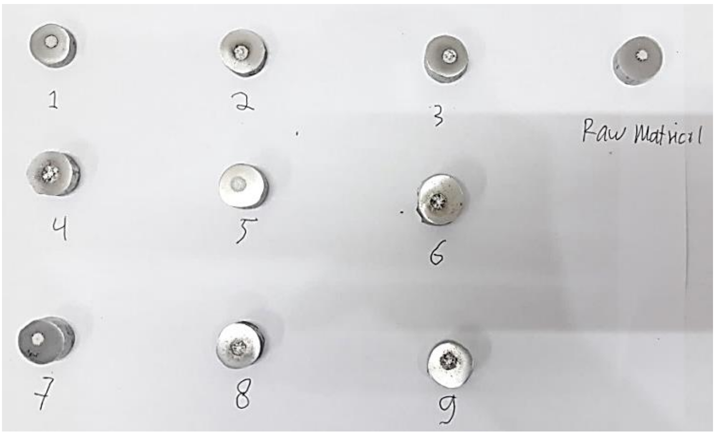

Figure 2. Samples of experiment runs

3. Analysis Based on Taguchi Method

Analysis of signal-to-noise ratio ($\frac{S}{N}$) and analysis of variance (ANOVA) are given as follow.

3.1. Analysis of signal to noise ratio

Signal-to-noise ratio indicates the output desirable value that are mean of output characteristics and noise indicates undesirable value such as squared deviation of output characteristics. S/N ratio denoted by η and the unit is dB. The equation for η for higher the best is given as equation 1.

$$\frac{s}{n} = -10 \times log \sum \frac{\left(\frac{1}{y^2}\right)}{n} \tag{1}$$

Table 3. L9 orthogonal array for experiment values

Experiment No.	Basalt (%)	Stirring Time (minutes)	Particle size (mesh)	Hardness (HRb)	S/N value (dB)	Mean
Raw				54.167		
1	5	5	100	141	42.9844	141
2	5	10	200	148	43.4052	148
3	5	15	325	151	43.5795	151
4	10	5	200	145	43.2274	145
5	10	10	325	145	43.2274	145
6	10	15	100	125	41.9382	125
7	15	5	325	148	43.4052	148
8	15	10	100	101	40.0864	101
9	15	15	200	149	43.4637	149

Analysis of variance (ANOVA) is a statistical analysis tool of data analysis. ANOVA includes the design parameters that significantly affect the output result. In the ANOVA method, the sum of square (SS), mean square (MS), and P values are calculated for deciding significant factors which affect the process and percentage contribution are calculated. The average effect response table for hardness and the rank of parameters as shown in Table 4 and Figure 3-4.

Table 4. Response table for signal to noise ratios (larger is better)

Level	A	B	C
1	43.32	43.21	41.67
2	42.80	42.24	43.37
3	42.32	42.99	43.40
Delta	1.00	0.97	1.73
Rank	2	3	1

Figure 3. Main effect plot for means

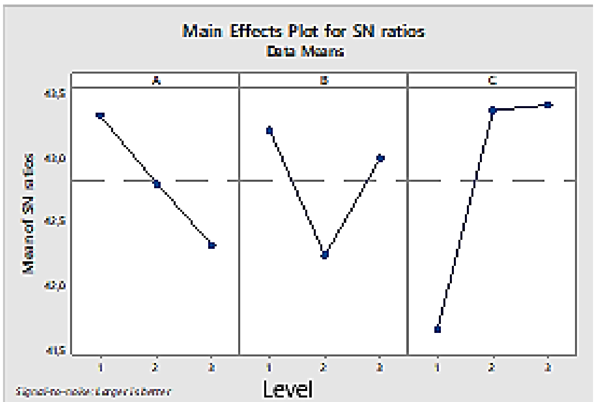

Figure 4. Main effect Plot for S/N Ratio

3.2. ANOVA
The percentage of contribution by each of the process parameters in the total sum of the squared deviation can be used to evaluate the importance of the process parameter change on the quality characteristic. In addition, P-value used in order to determine the accepted H_0 or rejected. Optimum process parameter and the effect of a factor on hardness material based on Taguchi analysis are the factor of percentage of basalt level one, stirring time level one and particle size (mesh) basalt level three. The most significant parameter according to ANOVA table is the percentage of basalt which affect the performance of material hardness. Basalt itself besides of high in silica content, the composition also high in other minerals such as Fe and Al which also can improve the mechanical properties of the composites [9]. Besides of the percentage of basalt, the significant parameter is particle size (mesh) of basalt and next is the stirring time. The percentage contributed by A (Basalt); B (stirring time) and C (particle size) are 18.62%, 8.45%, and 72.71% respectively. From the calculation prediction, particle size variable would highly affect in the hardness value of the composite. From the experiment, when the particle size is smaller, the hardness value is higher than the other samples with different variation. This is because if the particle size is smaller, the spreading of the particle is more homogenic towards the total surface area of the AMCs with stirring method. This result corresponds with the statement in Israa [10] and Jaya et al. [11], which is when the particle size is smaller, the mechanical properties of the composites are better.

Table 5. Analysis of variance for transformed response

Source	DF	Seq SS	Contribution **(%)**	Adj SS	Adj MS	F-Value	P-Value
A	2	278.19	18.62	278.19	139.096	86.09	0.011
B	2	126.17	8.45	126.17	63.083	39.05	0.025
C	2	1086.14	72.71	1086.14	543.071	336.14	0.003
Error	2	3.23	0.22	3.23	1.616		
Total	8	1493.73	100				

4. Conclusions
The Taguchi design can be used to analyse AMCs hardness test result which is made by stir casting method. ANOVA table determines the significance of stir casting parameters and according to ANOVA, the particle size do highly affect the hardness value which is the percentage of basalt. The second parameter that affects the hardness is the stirring time which it does less affect the hardness value. The experimental results correspond with the Taguchi method in term of the good materials quality and the hardness parameters in AMCs is optimized. Basalt particle would enhance the mechanical properties of AMCs, but the optimum value for enhancement especially in hardness can be achieved when the added particles is smaller.

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References
[1] Kala H, Mer K K S and Kumar S 2014 *Procedia Mater. Sci.* **6** 1951
[2] Lee W B and London W 1997 *Journal of Materials Processing Technology*. **63** 339
[3] Anam S 2012 *Kekerasan Dan Kekuatan Bending Komposit Aluminium Yang Diperkuat Serbuk Besi Produk Proses Stirring Casting* Diponegoro University Semarang. Indonesia
[4] Srivatsan T S, Ibrahim I A, Mohamed F A, and Lavernia E J 1991 *J. Mater. Sci.* **26** 5965
[5] Surappa M K 2003 Sadhana. **28** 319

[6] Arifin A and Juanidi 2017 *J. Tek. Mesin Untirta* **3** 21
[7] Raja M A, Manikandan V, Amuthakkannan V P, and Rajesh S 2018 *J Aust Ceram Soc* ***54*** 119
[8] Parihar R and Jathar S 2015 International Journal of Mechanical Engineering and Technology (IJMET) **6** 194
[9] Isnugroho, K., Hendronursito, Y. and Birawidha, D.C. 2018. Characterization and utilization potential of basalt rock from East-Lampung District. IOP Conf. Ser. Materials Science and Engineering 285(1):012014.
[10] Gh Israa 2017 Study the Effect of the Particle Size on Mechanical Properties of Particulate Natural Composite Materials.
[11] Jaya et al. (2016). "Sawdust polyethylene composites," BioResources 11(3), 6489 – 5504