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A STUDY OF WEAR AND HARDNESS PROPERTIES OF ALUMINUM MATRIX BAGASSE REINFORCED COMPOSITE

A. M. Aminu[1], O.B. Oloche[2], F.H. Tobins[3], I.D. Muhammad[4]
[1,2,3,4] Department of Mechanical Engineering, University of Abuja, Nigeria
Corresponding author: andaaminu@yahoo.com[1]phone: +2348063871231[1]

ABSTRACT

Hardness and wear properties of aluminium bagasse reinforced composite were studied. The composite was produced using stir casting route, the design of the experiment was carried out using the Taguchi method. Four processing parameters at four levels each were considered. The parameters are the weight of bagasse, melting temperature, stirring speed and stirring time. The aluminium 2024 alloy was the metal matrix formulated from the constituent elements and sugar cane bagasse ash was the reinforcement. L_{16} orthogonal array was selected for the study to obtain the optimal process parameters from the four-level chosen. Signal to noise ratio and ANOVA were used for the analysis of test data. The result so obtained shows that the weight of bagasse is the most influential and contributed majorly followed by the melting temperature for the wear rate and hardness properties. It was found that the optimum was at level 4, 3, 3, and 4 for the weight of bagasse, melting temperature, stirring speed and stirring time respectively for hardness property, but for the wear rate levels 1,4,2, and 3 are respectively the optimal level parameters.

***Keywords**: Wear resistance, hardness properties, Composite, Aluminium matrix, Bagasse ash, Process Parameter,*

1.0 INTRODUCTION

The use of aluminium-based matrix composites has wide applications in aerospace, satellite industries, structures, automobiles, and sports hardware for its lightweight, corrosion and wear resistance. However, the cost of synthetic reinforcement, scarcity and need to combat global warming have driven researchers to seek cheap and environmentally friendly alternatives (Safiuddin, Jumaat, Salam, Islam, & Hashim, 2010) and (Ajibola, Amori, & Dada, 2015). So, biodegradable materials like rice husk ash, pineapple leaf fibre, henequen, kenaf, jute, cottonseed, coconut husk, and bagasse ash are widely applied in various capacities (Silva, 2016). Sliding wear behaviour of aluminium matrix with Jute Blast as reinforcement was studied as reported in (Victor, 2017) and it was found that as the weight of Jute increased the wear rate reduced but increased with decreasing load. Rice husk ash was used as reinforcement in the aluminium matrix as reported in (Aigbodion, 2012) with improvement in the mechanical properties and reduction in weight. Furthermore, a study was conducted using both graphite and bagasse in aluminium 7075 matrix as discussed in (Dahal, Giri, Kharel, & Kumar, 2016) and the result was positive for hardness and ultimate tensile strength but negative for elongation.

Metal matrix composite has provided a great opportunity and better performance when compared with the polymer matrix and ceramic composites, in the area of ductility and toughness and high-temperature applications (Appusamy, Eswaran, & Subramani, 2018) and (Florea & Carcea, 2012). The aluminium metal matrix used in this study is known to be among high-quality materials for automobile and space applications because of the high strength to weight ratio (Toor, 2018) and (Arif, Asif, & Ahmed, 2017).

However, improvement for certain applications is required like hardness and wear resistance. So, bagasse a by-product of sugar cane is utilized as reinforcement in the form of ash and aluminium alloy (2000 series) as a matrix. Several studies have been published using Aluminium and bagasse as found in (Jajimoggala, 2018) and (Pirjade, Kulkarni, & Kulkarni, 2016), but this study is meant to herald the optimal process parameters in achieving the better hardness and wear resistance using Taguchi method of design of experiment, signal to noise ratio and ANOVA.

2.0 EXPERIMENTAL DETAILS

2.1 Materials and Equipment

Aluminium (A2024) alloy with two major constituents copper and magnesium was used as a matrix which was formulated from the aluminium-copper ligand, magnesium elements and aluminium offcut (rejects) wire which was sourced from NOCACO in Kaduna State, Nigeria. Bagasse was collected from the Madala market in Suleja, Niger State. The equipment used for this study include variable voltage speed controller, gas fired crucible furnace, thermocouple, timer, steel stirrer, standalone motor, sand mould, lathe machine, universal hardness tester, pin-on-disc tribometer, and sensitive digital weighing machine.

2.2 Methodology

First, the Taguchi method of design of experiment was adopted and used to design the experiment. With four factors and four levels, 16 experiments were planned and executed according to the DOE. Table 1 below was obtained from Minitab 17 statistical software. The process parameters considered for this study are the weight of bagasse in percentages, melting temperature, stirring time and stirring speed which are important control parameters for stir casting processes.

Table 1. Taguchi orthogonal array plan

Runs	Weight Of Bagasse (%)	Melt Temperature(°C)	Stirring Time (min)	Stirring Speed (rpm)
1	0	730	2	350
2	0	780	2.5	400
3	0	830	3	450
4	0	880	3.5	500
5	5	730	2.5	450
6	5	780	2	500
7	5	830	3.5	350
8	5	880	3	400
9	10	730	3	500
10	10	780	3.5	450
11	10	830	2	400
12	10	880	2.5	350
13	15	730	3.5	400
14	15	780	3	350
15	15	830	2.5	500
16	15	880	2	450

2.3 Stir Casting Process

Sixteen experiments were conducted according to Table 1 above. The crucible was charged with the aluminium offcut wire, aluminium-copper ligand, and magnesium elements after weighing. The total quantity of 400g (4.5% Copper, 1.6% Magnesium, bagasse weight was according to Table 1 and balanced with aluminium offcut), of the metals were melted in the crucible furnace, monitoring the temperature with thermocouple, and the preheated bagasse ash was introduced (the bagasse was previously charred in an open hearth and ash in a furnace at temperature of 1200^{o}C), stirred for some time and at the temperature provided by the plan for each experiment. After melting and stirring, the crucible was quickly and carefully lifted off the hearth and the content emptied into a previously prepared sand mould. The mould was allowed to cool down and the cast shaken out. The samples were then machined according to the specimen requirement for hardness test standard E18-15 (ASTM, 2015) and pin-on-disc wear test standard G99-05 (International, 2011).

2.4 Hardness Test

The hardness values were obtained by conducting the Rockwell Hardness test with an indenter universal hardness testing machine of model number: 8187.5LKV(B), indenter 1.588mm steel ball and preload of 10kgf. Measuring the diagonals of indentation on the material the result is displayed digitally. Three tests were carried out on the same sample at different points while the mean is recorded. The test was conducted for all other samples and the result tabulated as shown in Table 2.

2.5 Wear Test

Pin-on-disc test device was utilized to conduct the dry sliding wear characteristics of the aluminium bagasse composite according to ASTM G99-05 standards. A steel ball of 6mm dimension was pressed on the sample with a load of 5N, stop condition of 31.48meters and a linear speed of 10cm/s. The tribometer version is 6.1.19, **Anton Paar Austria GmbH**, Austria. The environmental temperature was 23^{o}C, and humidity 55%. Specimens of size 10mm diameter and 20mm length were cut from the cast samples, machined and then polished. The contact surface of the cast sample was made flat, rotating against a fixed pin. During the test, the pin was pressed against a rotating steel disc on which the sample was placed, applying a load that acts as counterweight and balances the pin. Once the surface in contact wears out, the load pushes the arm to remain in contact with the sample. The mass of the samples was taken before and after the test using the sensitive electronic weighing machine with an accuracy of 0.0001g after a thorough cleaning with acetone solution. The wear volume was then calculated and volume per minute obtained as shown in Table 5.

3.0 RESULTS AND DISCUSSION

3.1 Hardness Result and Discussion

The influence of each factor as shown in Tables 3 and 4 shows that the weight of bagasse is the most contributing factor and has the most critical effect on the hardness of the material. This is followed by a melting temperature. The ranking in Table 4 shows the weight of bagasse, melting temperature, stirring speed and lastly, the stirring time respectively in order of their significance. The percentage bagasse present provides blockade to the dislocation movement, the melting temperature affects the grain size and therefore has the most important effect on the hardness response. Figure 1 shows the impact of process parameters on the mean signal to noise ratio of the hardness of aluminium bagasse composite.

Table 2. Rockwell hardness response values

Runs	Weight Of Bagasse (%)	Melt Temperature (°C)	Stirring Time (min)	Stirring Speed (rpm)	Hardness (Rockwell)
1	0	730	2	350	40.1
2	0	780	2.5	400	39.5
3	0	830	3	450	42.4
4	0	880	3.5	500	41.1
5	5	730	2.5	450	52
6	5	780	2	500	52.7
7	5	830	3.5	350	54.9
8	5	880	3	400	52
9	10	730	3	500	55
10	10	780	3.5	450	53
11	10	830	2	400	54
12	10	880	2.5	350	54.6
13	15	730	3.5	400	56.2
14	15	780	3	350	55.5
15	15	830	2.5	500	56.7
16	15	880	2	450	56.4

Table 3. Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Weight Of Bagasse (%)	3	19.4076	19.4076	6.46919	195.81	0.001	97.7634
Melt Temperature (°C)	3	0.2253	0.2253	0.0751	2.27	0.259	1.134921
Stirring Time (min)	3	0.0486	0.0486	0.0162	0.49	0.713	0.244817
Stirring Speed (rpm)	3	0.071	0.071	0.02367	0.72	0.605	0.357654
Residual Error	3	0.0991	0.0991	0.03304			0.499204
Total	15	19.8516					

Table 4. Response Table for Signal to Noise Ratios (Larger is better)

Level	Weight Of Bagasse (%)	Melt Temperature (°C)	Stirring Time (min)	Stirring Speed (rpm)
1	32.2	34.05	34.04	34.12
2	34.47	33.93	34.02	33.97
3	34.67	34.26	34.14	34.09
4	34.99	34.09	34.14	34.15
Delta	2.79	0.33	0.12	0.17
Rank	1	2	4	3

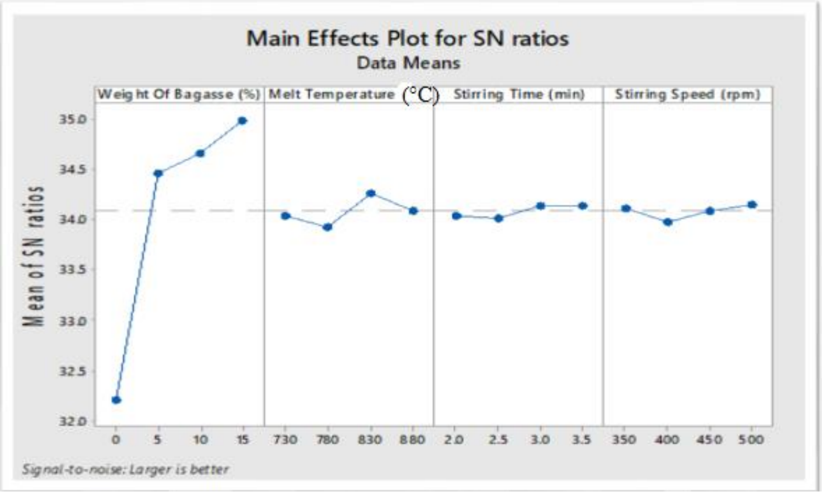

Fig 1: Impact of process parameters on the mean S/N ratio of the hardness of aluminium bagasse composite

Table 5. Wear result

Runs	Weight Of Bagasse (%)	Melt Temperature (°C)	Stirring Time (min)	Stirring Speed (rpm)	Wear Rate (mm^3/min)
1	0	730	2	350	0.110308
2	0	780	2.5	400	0.083436
3	0	830	3	450	0.261232
4	0	880	3.5	500	0.163436
5	5	730	2.5	450	0.138062
6	5	780	2	500	0.042687
7	5	830	3.5	350	0.176207
8	5	880	3	400	0.153744
9	10	730	3	500	0.063436
10	10	780	3.5	450	0.140616
11	10	830	2	400	0.126872
12	10	880	2.5	350	0.150749
13	15	730	3.5	400	0.022463
14	15	780	3	350	0.025374
15	15	830	2.5	500	0.063436
16	15	880	2	450	0.100308

3.2 Wear Test Result

The wear result in Table5 shows a reduction in wear rate as the weight of bagasse increases.

Further analysis presents the contribution and influence of the operating process parameters, the most influential parameter being the weight of bagasse, followed closely by the melting temperature then, the stirring speed and lastly the stirring time as demonstrated in Table 6, analysis of variance for the signal to noise ratios (S/N).

Table 6 Analysis of Variance for S/N ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Weight Of Bagasse (%)	3	248.103	248.103	82.701	13.12	0.031	44.7374
Melt Temperature (C)	3	186.027	186.027	62.009	9.84	0.046	33.544
Stirring Time (min)	3	4.659	4.659	1.553	0.25	0.86	0.8401
Stirring Speed (rpm)	3	96.878	96.878	32.293	5.12	0.106	17.4688
Residual Error	3	18.909	18.909	6.303			3.40963
Total	15	554.576					100

Looking at the response Table in Table 7 the optimal selection considering the four processing parameters simultaneously shows that the weight of bagasse with the least value coupled with other parameters with the least value is optimal since smaller is better was selected for the analysis. Figure 2 also presents the impact of the parameters on the mean S/N ratio of wear rate.

Table7. Response Table for Signal to Noise Ratios (Smaller is better)

Level	Weight Of Bagasse (%)	Melt Temperature (ºC)	Stirring Time (min)	Stirring Speed (rpm)
1	17.03	23.32	21.11	20.64
2	18.98	24.48	19.79	22.19
3	18.84	17.16	20.95	16.47
4	27.20	17.10	20.21	22.76
Delta	10.17	7.38	1.32	6.29
Rank	1	2	4	3

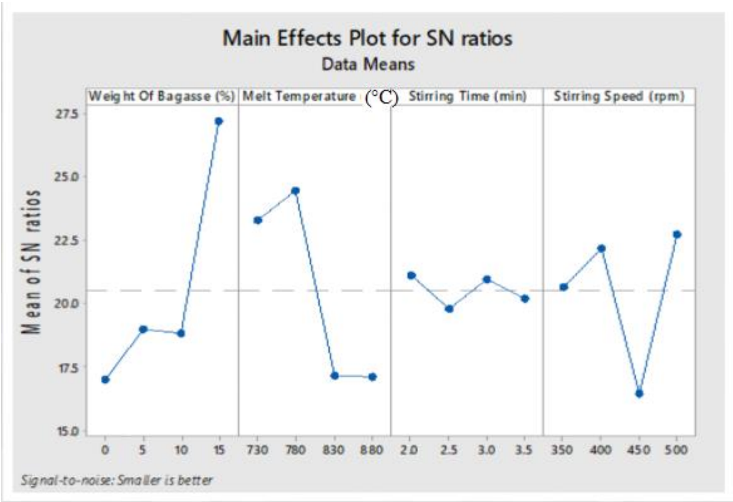

Figure 2: Impact of process parameters on mean S/N ratio of wear rate of the composite (aluminium bagasse reinforced composite)

4.0 CONCLUSIONS

The following are the conclusion from the study on the hardness test and wear test using the Taguchi method of design of the experiment.

1. The most influential and contributing parameter is the weight of bagasse for both wear and hardness test.

2. The use of bagasse as reinforcement increases the resistance to wear marginally and greatly for hardness of the composite. So, bagasse reinforcement does not provide a good wear resistance.

3. The optimum parameter for wear rate is level 1 for bagasse (0% weight), level 4 for melting temperature 880^{o}C, level 2 for stirring time 2.5min, level 3 for stirring speed 450rpm as presented in Table 7.

4. The optimum for hardness is level 4 (15% bagasse), level 3 (830^{o}C), level 3 (3min) and level 4 (500 rpm) which means that higher stirring speed reduces the grain growth tendencies thereby increasing hardness of the composite.

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