Optimizing Some Process Parameters in Aluminum Bagasse Ash Reinforced Composite

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Abstract- Optimization of process parameters in aluminum bagasse ash reinforced composite was studied using Taguchi L16 standard orthogonal array for the design of experiment, with the weight percentage of bagasse ash, melting temperature, stirring time and stirring speed as the control factors considered and impact and yield strengths as responses. Sixteen experiments were conducted through stir casting rout, impact and tensile tests were concluded on the samples. Analysis of variance (ANOVA) and the signal to noise ratio were analysed using the results of the tests. The analysis of variance and main effect plot show that the weight of bagasse is the most critical and contribute over 82% to the impact strength and over 96% to the yield strength. The signal to noise ratio reveals that the optimal parameters as 5% weight of bagasse, 730°C melting temperature, 2.5 minutes stirring time and 450 rpm stirring speed on the impact strength. The yield strength optimality according to Table 7 for the factors are 15% weight of bagasse, 880°C melting temperature, 2 minutes stirring time, and 500 rpm stirring speed. So, the weight of bagasse improves the mechanical properties of the composite, and sample 5 is the toughest of the materials having the highest impact Energy.

Keywords- aluminum alloy, bagasse ash, impact energy, optimization, process parameters, yield strength

1 INTRODUCTION

The study of process parameters and their interactions is vital in monitoring the mechanical properties of composites. Over a decade now, several works have been on one or two parameters and their effects are reported mostly based on one parameter at a time (Sozhhamannan, Prabu, and Venkatagalapathy, 2012). However, interactions of these parameters are critical in the outcome of the mechanical properties. The most commonly used metal matrix composites are aluminium-based metal matrix composites, this is as a result of the broad spectrum of engineering properties offered by aluminum at cheap and affordable processing cost. Among the common aluminum alloy series employed for composite fabrication are the 2000, 5000, 6000, and 7000 series mostly for improvement in strength requirement (ASM International, 2015), (Ram, Singh, and Sahib, 2013).

Aluminum matrix for a composite is widely used due to its excellent strength to weight ratio, and ductility. Aluminum alloy has vast engineering applications particularly in space industries, automobiles, marine components, sports equipment, and household utensils (Sunil, Keshavamurthy, Prakash, and Channabasappa, 2015). Bagasse ash composed mostly of oxides of silicon (SiO₂), iron (FeO₃), aluminum (Al₂O₃), and others as detailed by (Usman, Raji, Waziri, and Hassan, 2014). Bagasse used as reinforcement has provided an alternative for synthetic reinforcement like alumina (Al₂O₃) and silicon carbide (SiC), and widely available and cheap (Singh, Kumar, Kumar, Maurya, and Dwivedi, 2017). Bagasse, the chaff derived from sugarcane is abundant as sugarcane is cultivated worldwide, so the use of green materials like bagasse and rice husk in their ashes form welcome eco-friendly applications.

In this work, Taguchi L16 standard orthogonal array was used for the design of experiment. Similar adoption was reported in (Taguch, 1993), (Sylvester and Deepak, 2016), (Ahilan and Rajan, 2016), (Ramakoteswara, Ramanaiyah, Moulan, and Sarcar, 2016), stirring cast route was followed for this study. Four factors were varied. They were the weight percentage of bagasse, melting temperature, stirring time and stirring speed. Impact energy test response, and yield strength were measured. The results were analysed and optimized with analysis of the signal to noise ratio. The significance of the parameters, their contribution to the responses were analysed using ANOVA (analysis of variance).

2 MATERIALS AND METHODS

Aluminum alloy (2024) spectroscopic analysis in Table 1, used as the matrix of the composite was formulated from its major constituent elements which are copper and magnesium. Pure (99.9% Al) aluminum wire as off-cut was collected from NOCACO in Kaduna State. Aluminum-Copper ligand and magnesium metals were obtained from Metallurgical and Materials laboratory, Ahmadu Bello University (ABU) Zaria, Kaduna State, while the bagasse was obtained from Madala Market in Niger state. The bagasse was charred in an open fire, bagasse ash was produced by heating in a furnace for two hours at a temperature of 450°C -600°C to expel all combustible content Figures 1 and 2.

Deducing optimized properties from metal matrix composites requires detail understanding of all the processing parameters that shape the final responses, such as the volume fraction, morphology, size and shape of the reinforcement and possible reactions between them, operating temperature, stirring time and speed if liquid rout is pursued (Alaneme and Bodunrin, 2013).

Equipment used are: variable voltage controller (1-27 volts) was employed to vary the speed of the stirrer for homogeneity of the sample. Crucible furnace of capacity 1200°C was used for melting at controlled temperatures.
between 700°C - 900°C and monitored with a thermocouple, at the required temperature bagasse of certain quantity was introduced and stirred for a period of time. The sensitive electronic weighing machine (accuracy of 0.0000) was used in measuring the charging components. The sensitive electronic weighing machine (accuracy of 0.0000) was used in measuring the charging components. The liquid composite was then poured in a sand mould previously prepared, detailed design parameters for these casting is shown in table 2. Samples were produced, for each run, three samples 30 x10 cm were cast from the sand mould. The samples were then machined according to the ASTM standard for various testing machines. Hounsfield Tensometer (Model: W4729, made in the UK) was employed for the tensile tests. Figures 1 and 2 are open hearth char and bagasse ash as reinforcement for the composite.

### Table 1. Spectroscopic analysis of Aluminum alloy 2024 using Phenom World equipment

| Element Number | Element Symbol | Element Name | Weight Conc. |
|----------------|----------------|--------------|--------------|
| 13             | Al             | Aluminium    | 92.38        |
| 29             | Cu             | Copper       | 4.74         |
| 26             | Fe             | Iron         | 0.46         |
| 30             | Zn             | Zinc         | 0.12         |
| 11             | Na             | Sodium       | 0.09         |
| 12             | Mg             | Magnesium    | 1.65         |
| 14             | Si             | Silicon      | 0.45         |
| 16             | S              | Sulphur      | 0.04         |
| 23             | V              | Vanadium     | 0.03         |
| 15             | P              | Phosphorus   | 0.03         |
| 22             | Ti             | Titanium     | 0.01         |

### 2.1 IMPACT STRENGTH TEST

Balanced impact strength tester, Serial number: (3203). On a charpy mode was used for this test according to ASTM E23-18. The principle of the test varies from Izod test mode because the test sample was tested as a beam stutted at both ends, notched at the middle of one face, and the striker struck the other face precisely behind the notch. The broken samples and schematic diagram of the impact testing machine is shown in Figures 3 and 4.

### 2.2 TENSILE TEST

Hounsfield Tensometer (Model: W4729, made in the UK) was used for the tensile test based on ASTM E8/8M-13a. The loads were converted to stress by dividing by the area. At the point of yield, the corresponding stress is obtained and presented in Table 5. Broken samples of the tensile test are presented in Figure 5.

### Table 2. Experiment design, impact energy and SNR

| Samples | Weight Of Bagasse (%) | Melt Temperature (°C) | Stirring Time (Min) | Storing Speed (fps) | Impact Strength (Knots) | Signal To Noise Ratio | Impact Strength (dB) |
|---------|-----------------------|-----------------------|---------------------|---------------------|------------------------|-----------------------|-----------------------|
| 1       | 0                     | 750                   | 2                   | 350                 | 5.1742                 | 14.2749               |                       |
| 2       | 0                     | 810                   | 3                   | 400                 | 5.2005                 | 14.3209               |                       |
| 3       | 0                     | 830                   | 3.5                 | 450                 | 5.0813                 | 13.3183               |                       |
| 4       | 0                     | 880                   | 3.5                 | 500                 | 5.2814                 | 14.6719               |                       |
| 5       | 5                     | 750                   | 2                   | 450                 | 5.0841                 | 15.0859               |                       |
| 6       | 5                     | 780                   | 2                   | 500                 | 5.8075                 | 15.3991               |                       |
| 7       | 2                     | 830                   | 3.2                 | 320                 | 6.1099                 | 13.7205               |                       |
| 8       | 2                     | 840                   | 3                   | 600                 | 6.1052                 | 13.7587               |                       |
| 9       | 10                    | 750                   | 3                   | 600                 | 3.4592                 | 14.7217               |                       |
| 10      | 10                    | 780                   | 3.5                 | 450                 | 5.2454                 | 14.3954               |                       |
| 11      | 10                    | 780                   | 3.5                 | 400                 | 5.0889                 | 14.7419               |                       |
| 12      | 10                    | 800                   | 3                   | 370                 | 5.0871                 | 14.0784               |                       |
| 13      | 15                    | 750                   | 3                   | 600                 | 4.6675                 | 13.3817               |                       |
| 14      | 15                    | 780                   | 3                   | 450                 | 4.4234                 | 12.4742               |                       |
| 15      | 15                    | 830                   | 2                   | 500                 | 4.4234                 | 12.9212               |                       |
| 16      | 15                    | 850                   | 2                   | 450                 | 4.4234                 | 12.9212               |                       |
3 RESULT AND DISCUSSION

The impact energies of the samples were measured in joules using balanced impact strength tester. Signal to Noise ratio which is the measure of robustness or resistance to sensitivity, and can be used to know parameter settings that best minimizes the effect of uncontrollable factors. This was computed in Minitab via Taguchi method and presented in Tables 3 and 4.

The optimization objective is to maximize the response, so, larger is better is selected for the Taguchi Signal to Noise Ratios (S/N), so, the larger-the-better quality characteristic used is given in equation (1), (Ahamed, 2016), (Minitab, 2019).

\[
S/N = -10 \log \left( \frac{1}{n} \sum \frac{1}{y_i} \right)
\]  

(1)

Where \( Y \) = responses (impact strength, or Yield strength) for the given parameter level combination and \( n \) = number of responses in the parameter level combination.

The Result Response Table for Signal to Noise is presented in Table 3 which shows that level 2 of the bagasse 5% weight (S/N = 15.62), level 1 for melting temperature 730°C (S/N = 14.52), level 4 for stirring time 3 minutes (S/N = 14.53), and level 2 of stirring speed 400 rpm (S/N = 14.54) are the optimal combination of processing parameters for Charpy impact strength response.

Table 3. Response table for Signal to Noise Ratio by factor level Impact energies

| Level | Weight of Bagasse | Melt temperature | Stirring time | Stirring speed |
|-------|-------------------|------------------|---------------|---------------|
| 1     | 14.53             | 14.52*           | 14.33         | 14.14         |
| 2     | 15.82*            | 14.14            | 14.25         | 14.54*        |
| 3     | 14.49             | 14.28            | 14.28         | 14.28         |
| 4     | 12.93             | 14.34            | 14.53*        | 14.41         |
| Delta | 2.69              | 0.38             | 0.28          | 0.40          |
| Rank  | 3                 | 3                | 4             | 2             |

Table 4. Analysis of Variance for Impact Energies (ANOVA)

|                          | Degree of Freedom | Sum of Squares | Mean of Squares | F-Value | P-Value | Contribution (%) |
|--------------------------|-------------------|----------------|-----------------|---------|---------|------------------|
| Weight of Bagasse        | 3                 | 144391         | 48120           | 18.15   | 0.001   | 94.01774         |
| Melt Temperature         | 3                 | 0.2999         | 0.9998          | 3.66    | 0.157   | 1.890177         |
| Stirring time            | 3                 | 0.2032         | 0.6778          | 2.51    | 0.253   | 1.399499         |
| Stirring Speed           | 3                 | 0.3546         | 0.1182          | 4.42    | 0.127   | 2.341775         |
| Error                    | 3                 | 0.0268         | 0.0087          | 0.154   | 0.642   | 0.0154822         |
| Total                    | 15                | 153499         | 100             |         |         | 100              |

From Table 4 it can be deduced from the ANOVA for Impact energy that percentage weight of bagasse was the most critical parameter whose changes will affect the response immensely similar to the work of Khan as in (Khan, Anas, and Hussain, 2015). The mechanical properties of the composite increases as percentages of bagasse increases, next is the stirring speed followed by melting temperature and lastly stirring time. These facts were confirmed in the ANOVA shown in Table 4 and main effect plot in Figure 6 as similarly found in the work of (Prabu, Karunamoorthy, Kathiresan, and Mohan, 2006), for impact energy analysis, stirring speed is the next important factor.

The yield strength analysis presented in Tables 5 to 7, the p-value of the bagasse ash is 0.0000 which implied its critical role in the study and contributed to over 96% (Table 6 and Figure 8) influence in the overall yield strength of the composite. In Figure 8 and the Pareto chart Figure 7, weight of bagasse crosses the line signalling its important role in the yield strength of the composite. Melting temperature is the next crucial factor that must be given adequate attention among the factors.

Table 5. Design of Experiment, yield strength and S/N values

| WEIGHT OF BAGASSE (%) | MELT TEMPERATURE (°C) | STIRRING TIME (minute) | STIRRING SPEED | YIELD (Mpa) | SNR |
|-----------------------|-----------------------|------------------------|----------------|-------------|-----|
| 0                     | 730                   | 2                      | 500            | 139.0000    | 42.8650 |
| 0                     | 780                   | 2.5                    | 400            | 139.0000    | 42.8790 |
| 0                     | 830                   | 3                      | 450            | 142.4400    | 43.6781 |
| 0                     | 880                   | 3                      | 500            | 142.2640    | 43.06195 |
| 5                     | 730                   | 2                      | 450            | 147.9060    | 43.3655 |
| 5                     | 780                   | 2                      | 500            | 148.9637    | 43.5813 |
| 5                     | 830                   | 3                      | 390            | 149.8557    | 43.4582 |
| 5                     | 880                   | 2                      | 400            | 149.7042    | 43.4014 |
| 10                    | 730                   | 3                      | 500            | 152.6429    | 43.6777 |
| 10                    | 780                   | 3.5                    | 450            | 152.9425    | 43.6986 |
| 10                    | 830                   | 2                      | 450            | 154.7257    | 43.7912 |
| 10                    | 880                   | 2.5                    | 350            | 155.9779    | 43.7417 |
| 15                    | 730                   | 3                      | 400            | 160.8683    | 43.1941 |
| 15                    | 780                   | 2                      | 390            | 162.4702    | 44.3746 |
| 15                    | 830                   | 2.5                    | 300            | 164.7964    | 44.3737 |
| 15                    | 880                   | 2                      | 450            | 167.5302    | 44.48064 |

Table 6. Analysis of variance for SN ratios for yield strength

| Source                  | DFE | SS   | MS   | F     | P-Value | Contribution (%) |
|-------------------------|-----|------|------|-------|---------|------------------|
| Weight of Bagasse      | 3   | 3.60073 | 1.20024 | 2.3203 | 0.123   | 2.023477         |
| Melt Temperature       | 3   | 0.09001 | 0.03000 | 0.1027 | 0.740   | 0.066265         |
| Stirring time          | 3   | 0.01757 | 0.00586 | 0.0898 | 0.719   | 0.058684         |
| Stirring Speed         | 3   | 0.01931 | 0.00644 | 0.0736 | 0.850   | 0.039798         |
| Residual Error         | 3   | 0.00689 | 0.00023 | 0.0076 | 0.930   | 0.000289         |
| Total                  | 15  | 3.7612 | 100   |       |         | 100              |
Table 7. Response Table for signal to noise ratio Larger is better for yield strength

| Level | Weight of Bagasse | Melt Temperature | Stirring Time | Stirring Speed |
|-------|-------------------|------------------|---------------|---------------|
| 1     | 42.97             | 43.51            | 43.66*        | 43.58         |
| 2     | 43.46             | 43.56            | 43.58         | 43.57         |
| 3     | 43.71             | 43.67            | 43.61         | 43.64         |
| 4     | 44.29             | 43.69*           | 43.56         | 43.65*        |

Delta 1.32 0.19 0.08 0.08

Rank 1 2 3 4

*Optimal values

Fig. 7: Pareto chart of the Effect of factors on Yield strength

Fig. 8: Main Effects Plot for Signal to Noise Ratios on Yield strength

4 CONCLUSION

i. The optimal process parameters for the Impact Strength are 5% weight of bagasse, 730°C melting temperature, 3 minutes stirring time, and 400 rpm stirring speed. So, the weight of bagasse improves the Impact energy of the composite, therefore sample 5 is the toughest of the materials.

ii. The most critical parameter for the impact strength is the weight of bagasse as shown in the ANOVA and main effect plot for the signal to noise ratio, this was followed by stirring speed.

iii. The yield strength optimality according to Table 6 for the factors were 15% (level four) weight of bagasse, 880°C melting temperature, 2 minutes stirring time, and 500 rpm stirring speed.

iv. Pareto Chart and Main Effect plots show that 15% bagasse is the major effect factor that influences the yield strength.

v. From these results, it is quite clear that the composite can be applied in the structure subsystem of satellite and other space structural applications.

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