OPEN ACCESS Journal

International

Of Modern Engineering Research (IJMER)

Tensile Properties of Recycled Aluminium Cans Reinforced with Rice Husk Ash: Optimization of Process Parameters

A.A Yekinni*, T.O Rabiu, I.A Adigun, O.D Sogunro, R.OSaheed,

Department of Mechanical Engineering, Lagos State Polytechnic, Ikorodu, Lagos, Nigeria

**Corresponding Author:A.A Yekinni*

ABSTRACT:*In recent time, optimization processes for optimizing conditionscan be achieved by application of a number of statistical tools. Such tools include response surface methodology (RSM), Taguchi, factorial design, regression analysis, analysis of variance (ANOVA) etc. In the present study, a three factor historical data, response surface methodology was used as a logical and sequence of design experiments to achieve an optimal response purpose to investigate the influence of tensile properties of stir cast composites. The composites were prepared from recycled aluminium cans and rice husk ash (RHA) by varying stir casting parameters like stirring time (10, 20, 30 min), particle size (150, 300, 600 µm), and weight percentage (wt. %) of RHA reinforcement (5, 10, 15 %). The contribution of each input process parameters on the tensile strength was analyzed by using ANOVA. The results have shown that the wt. % of RHA, stirring time and the particle size of RHA have a significant effect on the tensile strength. However, fromANOVA test,particle size of 150 µm is the most influential parameter on the tensile strength results of the castings. Optimal result was obtained at weight fraction of 10 %, particle size of 150 µm and stirring time of 30 minutes. Finally, model equation was developed while confirmation test was done to verify predictive model with the experimental results. The confirmation test revealed that the resulting regression equations is capable of predicting the tensile strength to the acceptable level of accuracy.*

KEYWORDS: *Optimization, Analysis of Variance, Historical data, Process Parameters, Response Surface Methodology*

Date of Submission: 18-12-2018 Date of acceptance: 31-12-2018

I. INTRODUCTION

Metal matrix composites are used for engine cylinders, pistons, disc and drum brakes, cardan shafts and for other components/elements that find applications in automotive, aviation and manufacturing industries. The most widely used of all the metallic materials is composite materials with matrices of aluminium alloys as a result of several beneficial physical and mechanical properties [1-4]. However, defects such as low temperature capability, high thermal expansion coefficient and inadequate mechanical, and tribological characteristics limit the use of monolithic aluminium alloy in automobile and aerospace industries.

Improvement of physical and mechanical properties of composites were provided by the use of certain reinforcement such as Silicon Carbide (SiC), Alumina (Al_2O_3), Boron Carbide (B_4C), Tungsten Carbide (WC), Graphite (Gr), Carbon Nanotubes (CNT) and Silica (SiO_2) either in single or hybrid forms in defined weight or volumetric share [5,2,6-7].

Most engine parts of automotive and aerospace are subjected to operations in very hard dynamical, thermal and mechanical conditions. These parts are mostly loaded to cyclic mechanical load with frequency of over 100 Hz, such that fatigue and other sources of damages are primarily important for consideration for better use. Dynamic endurance, high resistance to wear and thermal expansion coefficient are necessary characteristics of materials for automotive and aerospace engines. Most engines operate at temperatures up to 3000°C which may result in high temperature gradients and thermal cycles, and as such, high thermal conductivity must be provided in order to reduce temperatures and thermal impacts [7].

However, present demand in automotive and aerospace industries require development of a composite with aluminium matrices having broad spectrum of properties for wide industrial applications, better in-service and engine performance. These combinations of properties can be achieved through development of a novel composite of aluminum which are stronger, lighter and less expensive with higher strength, higher hardness, good strength to weight ratio, improved impact strength, higher temperature capability, higher thermal conductivity and higher resistance to fatigue.

Rice husk is presently considered as an agricultural waste in which burning is the primary means of disposal. Not only does burning create pollution problems but the extremely fine silica is also toxic and thus constitute health hazard. Thus, the associated problems of air pollution and ash disposal has shown that burning in open air is an unacceptable method of rice husk disposal. Fortunately, rice husk is an ideal source of material for producing SiC, an industrially important ceramic material because it contains carbon and silica, intimately dispersed. It was reported by [8] that [9] was the first person to use rice husk as a starting material for the production of SiC.

Optimizing the production process using different process parameters will also provide new information and knowledge in the development of aluminium matrix composites and offer more flexibility in the design of different components. Optimization techniques are powerful set of tools so important in efficiently managing input parameters thereby maximizing output. Sujik [10] defines optimization as a technique employ in finding out the right level or value of parameters that have to be maintained for obtaining quality output. The basic form of the problem is to identify the alternative means of achieving a given objective and then to select the alternative that accomplishes the objectives in a manner that is most efficient subject to constraint on the means. Also, in programming terminology, the problem revolves around optimizing the values of some objective function object to some constraints. In optimization process, the objective function expresses the desired aims of the process clearly and understandably. In comparing with the model which is fixed by the physical characteristics of the system, it expresses the wishes with regard to the final product and the performance of the process. Certain number of factors can make optimization problem fairly complex and difficult to solve. One of such complex situations is the existence of multiple decision variables which must be incorporated into decision problem, otherwise, the optimization technique that are applied to the problem may result a solution that is unacceptable from a real practical point of view.

However, in recent time a number of statistical tools are applicable in optimization processes for optimizing conditions. Such tools include response surface methodology (RSM), Taguchi, factorial design, regression analysis, ANOVA etc. Therefore, it is a very important usable thing to do in the industry to optimize the materials and processes for obtaining metal matrix composites (MMC). Reinforcing the metal matrix with high strength materials, the composite may appear very brittle. The reinforcement can also have thermal dynamic incompatibility with many metals used as matrix [11].

As a result of this, Luo [12] suggested that in the solidification processing of metal matrix composites, it is of utmost importance to ensure that the process parameters are optimized both to avoid excesses interfacial reactions and at the same time achieve wetting so that a uniform particle distribution and interfacial bonding are obtained. Lakhviret al [13] used Taguchi method to optimize process parameter for hardness, impact strength and tensile strength for stir casted aluminium metal matrix composite.

The aim of the study is to reinforce recycle aluminium alloy with rice husk ash to develop a composite of aluminium metal matrix with superior mechanical properties suitable in the production of aerospace, automotive components and industrial parts. A theoretical and experimental framework for the development of Aluminium alloy metal matrix composites (AMMC's) reinforced with rice husk ash shall be provided while the production of the Al/RHA composites shall be optimized using Response Surface Methodology (RSM).

II. MATERIALS AND METHODS

The methodology of this research involves preparation of metal matrix (base metal) and reinforcements, preparation of composites and specimens, selection of test methods and test conditions, experimental measurement oftensile strength of the specimens, Model development and validation using experimental results. Three different particle sizes 150 µm, 300 µm and 600 µm were used in different wt. % 5, 10 and 15 at stirring time of 10, 20 and 30 minutesat constant stirring speed of 140 rpm used in manufacturing of the composites of Al-RHA.

The matrix material selected for the study is recycled aluminium cans which was sourced from local markets in Ikorodu, Lagos. The rice husk (RH) which is the reinforcing material was sourced from local rice mills at Imota town in Lagos state.

A three factor, Historical Data (HD) model was used to design the experiment. Design-Expert version 6.0.8 was used for the modeling of the identified variables. The factors considered were weight fraction, particle size, stirring speed and stirring time while the response is tensile strength. The experimental range of the variables used to design the experiment for the modelling is tabulated (Table 1).

Table I. Design of factors of Stir casting process at Stirring time of 140 rpm

Factors	Code	Level		
		Low (-1)	Standard (0)	High (+1)
Weight fraction (%)	A	5	10	15
Particle size (µm)	B	150	300	600
Stirring time (minutes)	C	10	20	30

2.1 Preparation of Rice Husk Ash

The variety of indigenous rice grown in Nigeria include, Fadama rice, Upland rice and Lowland rice. Fadama rice, a variety of red grain specie (oryzaglaberrina) was used in this study. The rice husk comes with some rice grains, adhering sand particles and other contaminants mixed together both in particles and powder form which has to be separated before use.

The mixture was first blown manually to separate the husk from rice grains and other contaminants and then washed with tap water twice by stirring in a container to allow the sand impurity and rice particles to settle at the bottom while the powdered grains and sand mixed with the water became muddy. This muddy water was then poured away and the rice husk was manually removed from the container leaving behind the settled sand. The blown, washed and dried rice husk wasplaced inside a crucible pot and burnt at 700^{o}C for four hours inside the muffle furnace into ashes. The ash was sieved and graded (fig. 1a) into three different particle sizes of 150 µm, 300 µm and 600 µm.

2.2 Preparation of Aluminium Billet andAluminium/Rice Husk Ash Composites

Stir- casting technique was used to prepare the aluminium billet and the composite. This method could distribute rice husk ash particles homogenously in the aluminummicrostructure by forming vortex in molten metallic. It could pull RHAparticles through molten metallic and distribute them homogenously.

A trapezoidal aluminium bar matrix material was produced from recycled aluminium cans in a crucible furnace and cast into small billet to obtain the requiredweight according to reinforcement rice husk ash particles weight fraction (5, 10, and 15 wt. %).

To produce the Al/RHA composites, as-cast trapezoidal aluminium bar of 1000 g, 995 g, 910 g and 985 g (fig. 1b) was prepared for control sample, and 5, 10 and 15 % Al/RHA composites respectively and for average particle size RHA(150 µm, 300 µm, 600 µm).

The melting was carried out in a crucible pot placed inside the crucible furnace. Each aluminium alloy billet melted was first preheated at 450^{o}C before melting at 750^{o}C and rice husk ash of the required percent weight fraction and particle size was measured and preheated to about 100^{o}C before incorporating into the melt which was then degassed to control the porosity

To enhance the wettability between the rice husk particles and alloy melt, 1 wt% of magnesium is simultaneously added into the molten melt. Saravanan and Kumar [14], stressed that particles of rice husk ash will be rejected without addition of magnesium.

The molten metal was stirred by the improvised stirrer at a speed of 140 rpm for the required time. The mixture is poured into the cylindrical and rectangular die moulds which has been preheated to about 200 ^{o}C before pouring. During pouring in the metal mould, slag and any form of impurity was removed.

(a) (b)

Figure 1: (a) Graded rice husk ash (b) As-cast aluminium Alloy bar

2.3 Specimen Preparation and Test

The tensile test specimen was prepared on a lathe machine from cylindrical sample to determine the tensile strength (fig. 2a and b). The tensile test was carried out at room temperature on HZ-1009 Computer Servo Universal Testing Machine, by Dongguan Lixian Instrument Scientific Company Limited.

Following standard test procedures in accordance with the ASTM E8 (2008), the sample was fixed in the tensile testing machine at EMDI Akure, and a pulling force is applied to the steel axially. Each test was performed 2 times to avoid first time error. The tensile properties evaluated from the engineering stress-strain curves developed.

(a) (b)

Figure 2: (a) Cylindrical casting for machining tensile specimens (b) Tensile Specimen

III. RESULTS AND DISCUSSION

Tables 2, 3 and 4 show the chemical composition of RHA, composition of aluminium ingot and tensile test results respectively.

Table II: Percentage chemical composition of rice husk ash burnt at 700°C

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_2	K_2O	Na_2O	Others	LOI
97.095	1.135	0.316	0.073	0.825	0.146	0.181	0.092	Balance	0.965

Table III: The elemental composition of the as cast aluminium alloy ingot.

Al	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ni	Ti
95.24	0.66625	1.861	0.0953	0.8382	0.8565	0.0252	0.0168	0.1194	0.035
Sr	**Zr**	**V**	**Ca**	**Be**					
0.000	0.008	0.0153	0.0127	0.000					

Table IV: Design of Parameters and responses for Al/RHA Composites(control sample is 148 MPa)

Std	Run	Block	Factor 1 A:Weight Fraction %wt	Factor 2 B:Particle Size	Factor 3 C:Stirring time Mins	Response Ultimate Strength MPa
3	1	Block 1	5	600	10	150.00
4	2	Block 1	5	150	20	170.00
8	3	Block 1	15	150	30	179.72
7	4	Block 1	15	300	10	165.20
5	5	Block 1	10	600	10	158.00
2	6	Block 1	5	300	30	160.00
6	7	Block 1	10	300	20	162.09
9	8	Block 1	10	150	30	180.10
1	9	Block 1	15	600	20	152.00

3.1 Statistical Data Analysis

Analysis of variance (ANOVA) was used for the analyses of the data obtained from Al-rice husk ash composites. The interactions between the process variables and the responses of different regression models developed for tensile strength, impact strength, were investigated. The quality of the fit polynomial model was expressed by the coefficient of determination $R^2$and its statistical significance was checked by the Fisher's F-test in the same in-built statistical program of the Design Expert 6.0.8. Model terms were evaluated by the p-value (probability)with 95% confidence level. Three-dimensional surface plots and their respective contour plots were obtained for tensile strength, impact strength, on the effects of the three factors (weight fraction, stirring time and particle size) at constant stirring speed of 140 rpm.

The Analysis of variance for the analytical design was shown in Table 5. The Model F-value of 561.32 implies the model is significant. Values of "Prob > F" less than 0.0500 indicate model terms are significant. All model terms were significant at $p<0.05$ except the combination of weight fraction and stirring time (AC). In term of individual parameter, particle size (B) shows the most significant effect on Ultimate Tensile Strength of the Al alloy sample reinforced with Rice Husk, having the highest F-value and corresponding low p-value. This was followed by weight fraction and least significant effect was observed in stirring time.

The interactive effect of particle size and stirring time gave the highest significant effect on the Al/RHA sample tensile strength with the highest F-value of 385.61 and 0.002 p-value. Combination of weight fraction and stirring time gave no significant effect on the ultimate strength of the Al/RHA sample, having p-value greater than 0.05. Values greater than 0.1000 indicate the model terms are not significant.

Table 6 shows the evaluation result of the developed and analyzed model. High correlation coefficient R^2 of 0.9994 indicates the accuracy of the model. The "Pred R-Squared" of 0.9775 is in reasonable agreement with the "Adj R-Squared" of 0.9976. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The model ratio of 64.95 indicates an adequate signal.

The model equation developed is as shown in equation 1:

Ultimate Tensile Strength =+148.34886 -0.028831 * A +0.010215* B +1.72274 * C +3.07898E-003 * A * B -0.011559* A*C -5.07187E-003 * B * C……………………………………….(1)

Where A = Percent weight fraction, B = Particle size and C = Stirring time

Table V: ANOVA for response surface 2FI Model for Ultimate Tensile Strength

Source	Sum of Squares	DF	Mean Square	F Value	Prob> F	
Model	938.7115	6	156.4519	561.318	0.0018	Significant
A	100.6923	1	100.6923	361.2637	0.0028	
B	487.0945	1	487.0945	1747.597	0.0006	
C	19.82155	1	19.82155	71.11574	0.0138	
AB	23.78529	1	23.78529	85.33684	0.0115	
AC	0.739796	1	0.739796	2.65424	0.2448	
BC	107.4787	1	107.4787	385.6119	0.0026	
Residual	0.557445	2	0.278722			
Cor Total	939.2689	8				

Table VI: Model Estimation Result for Ultimate Tensile Strength

Std. Dev.	0.527942	R-Squared	0.999407
Mean	164.1239	Adj R-Squared	0.997626
C.V.	0.321673	Pred R-Squared	0.97751
PRESS	21.12422	Adeq Precision	64.95913

3.2 Confirmation Test

The confirmation test was conducted by selecting the set of parameters utilized with the levels of the optimal casting parameters at 10% weight fraction, 150μm particle size and stirring time of 30 minutes for tensile strength value in the casting of Al/RHA composites. Based on data set, experiments were conducted and their results were noted. Then, a comparison was made between the experimental values and the computed values obtained from the regression model. Calculated value of 179.61 MPa from the regression equation and the experimental value of 180.10 MPa for the tensile strength of the composites are nearly the same with the least error (±5%). The resulting regression equations seem to be capable of predicting the tensile strength to the acceptable level of accuracy.

Fig.3 show the diagnostic plots of residuals against the normal probability and the predicted values against the actual values. Datapoints aligned with the straight line with little overfitting in the residual plot and perfect linear plot in the predicted aginst actual plot to indicate adequate model analysis.

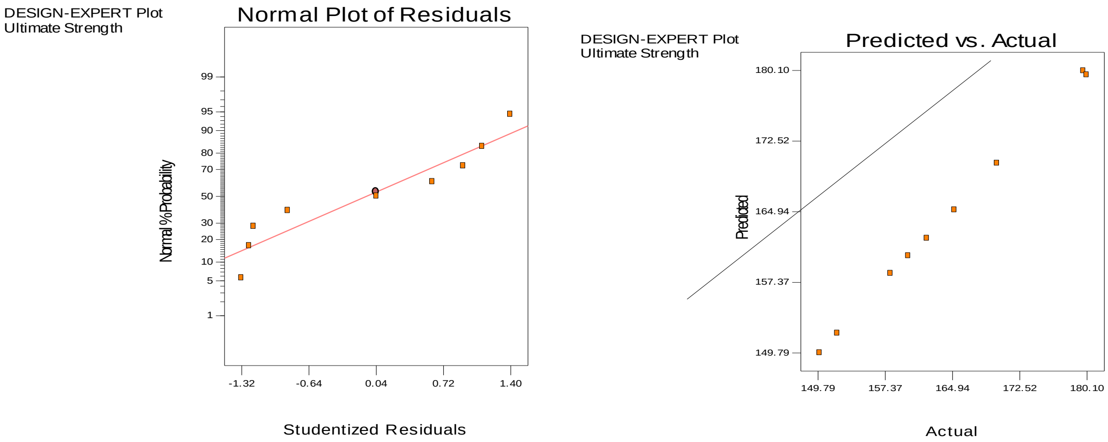
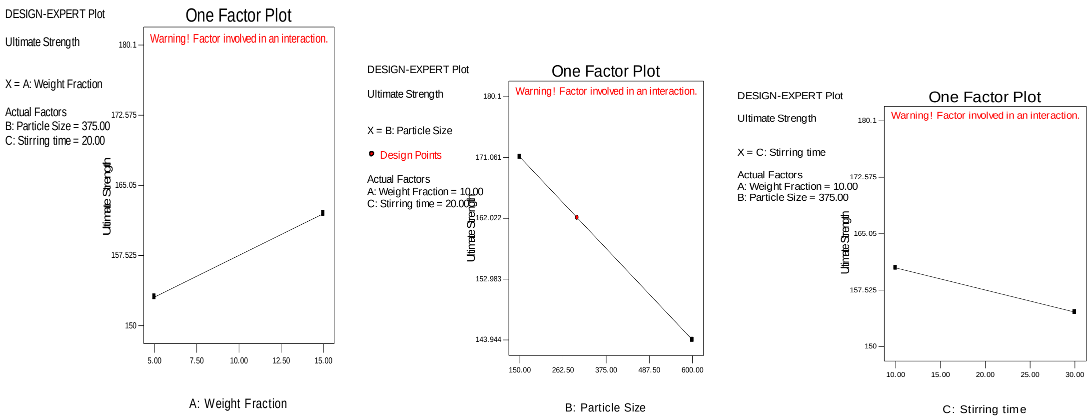


Figure.3: Diagnostic plots of developed ultimate tensile strength model

3.3 Effect of Single Variable on the Al/RHA Composite Ultimate Tensile Strength

Fig. 4a - c show the effects of independent variables on the ultimate tensile strength of the Al/RHA sample. Ultimate tensile strenght increased with increase in weight fraction but decreased with increase in both particle size and stirring time.



(a) (b) (c)

Figure.4: Plots of (a) weight fraction, particle size and stirring time against Ultimate Tensile Strength

3.4Effect of Weight Fraction and Paricle Size on Ultimate Tensile Strength

The interactive effect of weight fraction and particle size on the ultimate strength at constant stirring time of 20minutes was shown in Fig.5a. At low particle size 150µm, the ultimate strength of the material tends toward linearity as weight fraction increases. At 600µm size, ultimate strength increased from 136MPa to 151.8MPa as weight fraction increases from 5-15%.

3.5 Effect of Weight Fraction and Stirring Time on Ultimate Tensile Strength

Fig.5b shows the combined effect of weight fraction and stirring time on the ultimate tensile strength, keeping particle size constant at 300µm. It was observed that ultimate strength of the Al/RHA sample increased at low stirring time from 155MPa to 165.5MPa as weight fraction increases from 5-15%. This same behaviour was seen at high stirring time 30mins as the Al alloy composite strength increased from 150.6MPa to 158.4MPa. Therefore, high strength of the reinforced composite sample is favoured by low stirring time (10mins) and high weight fraction of 15%.

3.6 Effect of Particle Size and Stirring Time on Ultimate Tensile Strength

Fig.5c shows the synergetic effect of particle size and stirring time on the ultimate tensile strength of the composite material at constant weight fraction of 10%. At low stirring time of 10minutes, it was observed that ultimate strength decreased slightly from 162MPa to 158MPa as particle size increases from 150-600 µm. But at high stirring time of 30mins, the Al/RHA strength decreased greatly from 179MPa to 129MPa with increase in particle mesh size. This therefore indicated that high strength is favoured by high stirring time 30mins and low particle size 150µm.

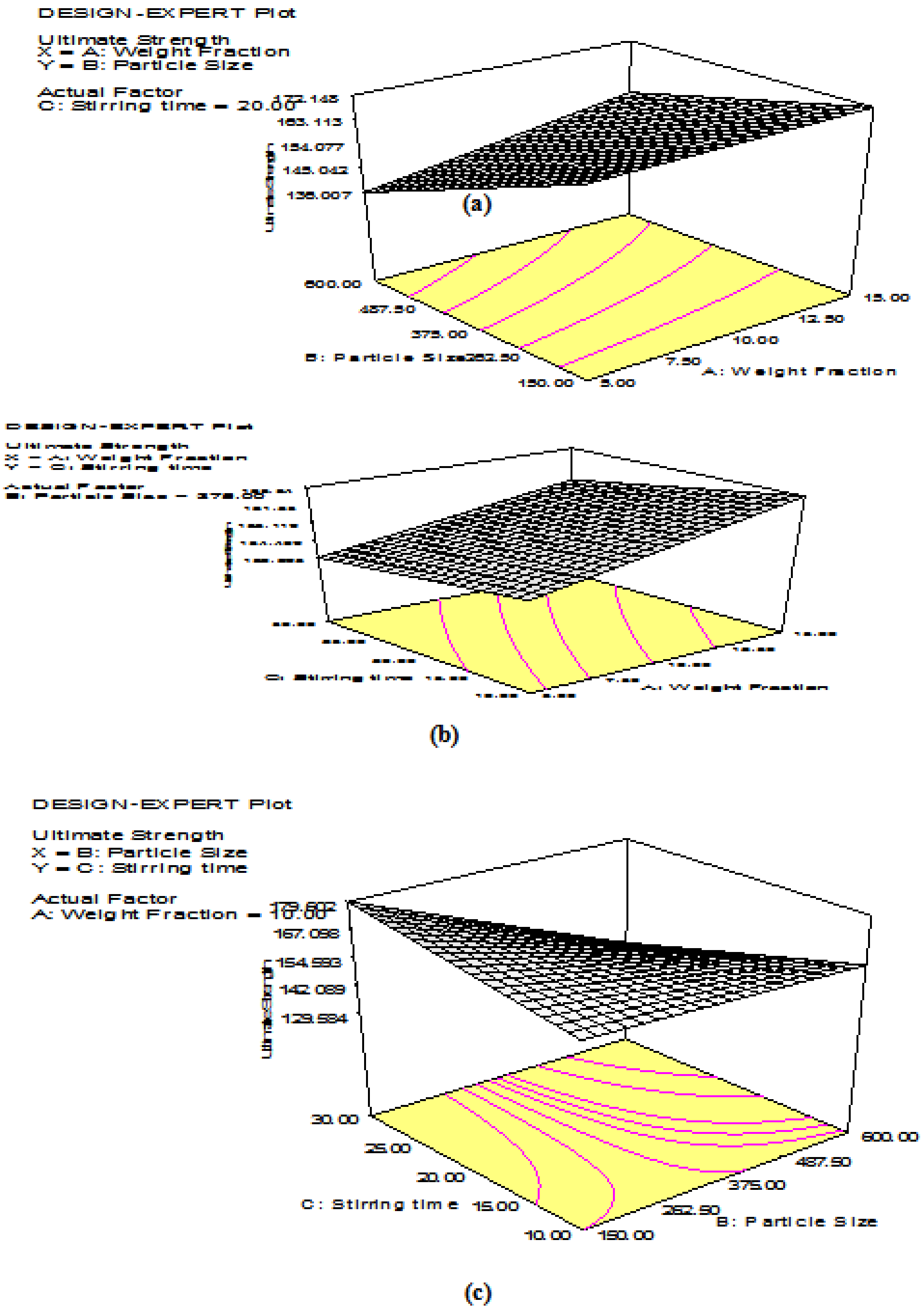


Figure 5: (a) Response surface plots of particle size and weight fraction against Ultimate Tensile Strength (b) Response surface plots of stirring time and weight fraction against Ultimate Tensile Strength (c) Response surface plots of stirring time and particle size against Ultimate Tensile Strength

IV. CONCLUSIONS AND RECOMMENDATIONS

The recycled aluminum reinforced with RHA at different level and parameter was successfully produced by stir casting method.From the analysis of the results in the casting process using the conceptual signal-to-noise (S/N) ratio approach, analysis of variance (ANOVA), and Response Surface Method, the following can be concluded from the present study:

1. The composites containing recycled Al alloy with 5, 10 and 15 wt. % of RHA particulates were successfully synthesized by stir casting technique.

2. The optimum level of casting parameters to obtain goodtensile strength for stir casting Al /RHAcomposites are 10 % weight fraction, 150 µm particle size and 30 minutes stirring time constant stirring speed of 140 rpm for tensile strength.
3. Particle size of 150 µm has major effect on the tensile strength of the composites.
4. Response Surface method has proved its success in predicting theoptimum casting parameters to reach the best properties.
5. Confirmation experiment was carried out and a comparison was made between experimentalvalues and computed values, showing an error associated withtensile strengthof composites was observed as less than 0.5 %. Thus, the response surface method was successfully used.
6. It is recommended that a hybrid composite of Al/RHA be produced using nanoplatelets reinforcement for improved mechanical and thermal properties.

REFERENCES

[1]. Prasad S.V. and Asthana, R. (2004).“Aluminum Metal–Matrix Composites for Automotive Applications: Tribological Considerations”. Tribology Letters, 17, 445-453.
[2]. Stojanovic B and Babic M (2014).“Optimization of A356/10SiC/3Gr Hybrid Composite Wear Using Taguchi Method”.8th International Conference on Tribology, Sinaia, Romania, pp 708-715.
[3]. Miracle D.B. (2005).“Metal Matrix Composites-From Science to Technological Significance”. Composites, Science anf Technology, 65, pp 2526-2540.
[4]. Stojanović B., Babić M., Mitrović S., Vencl A., Miloradović N., Pantić M. (2013).“Tribological characteristics of aluminum hybrid composites reinforced with silicon carbide and graphite. A review”. Journal of the Balkan Tribological Association, 19, pp 83-96.
[5]. Vencl A. (2012).“Tribology of the Al-Si alloy based MMCs and their application in automotive industry”, Magagnin L. (ed.), Engineered Metal Matrix Composites: Forming Methods, Material Properties and Industrial Applications, Nova Science Publishers, Inc., New York (SAD), 127-166.
[6]. Vencl A., Bobic I and Stojanovic B (2014).“Tribological properties of A356 Al-Si alloy composites under dry sliding conditions”, Industrial Lubrication and Tribology, 66, pp 66 – 74.
[7]. Stojanovic B. and Ivanovic L. (2015).Application of Aluminium Hybrid Composites in Automotive Industry, Technical Gazetti, 22,1 pp 247-251.
[8]. Singh S.K., Mohanty B.C. and Basu S. (2002).“Synthesis of SiC from Rice Husk in a Plasma Reactor”. Bull. Material Science, Indian Academy of Sciences, Volume 25, No 6, pp 561-563.
[9]. Cutler I.B (1973).“Production of Silicon Carbide from Rice Hull”. United State Patent Office, Ser. No 85,698, Int. Cl. C01b, 31/36, 53/02, 47/00, pp 423-345.
[10]. Sujit K.J. (2014).“Optimization of Process Parameters for Optimal MRR during Turning Steel Bar using Taguchi Method and Anova”, International Journal of Mechanical Engineering and Robotic Research, Volume 3, No 3, pp 232-243.
[11]. Peters S.T (1998).“Handbook of Composites”. 2nd ed., Chapman & Hall, London.
[12]. Luo A (1995).“Processing, microstructure, and mechanical behavior of cast magnesium metal matrix composites”. Metallurgical and Material Transaction A, Volume 26, Issue 9, pp 2445-2455.
[13]. Lakhvir S, Balyyinder R, Amandeep S (2013).“Optimization of Process Parameters for Stir Casted Aluminium Metal Matrix Composite Using Taguchi Method”. International Journal of Research in Engineering and Technology, Volume 02, Issue 08 pp 375-383.
[14]. Saravanan S.D and Kumar M.S (2013). “Effect of Mechanical Properties of Rice Husk Ash Reinforced Aluminium Alloy (AlSi10Mg) Metal Matrix Composites”. Procedia Engineering, 64, pp 1505-1513.

A.A Yekinni" Tensile Properties of Recycled Aluminium Cans Reinforced with Rice Husk Ash: Optimization of Process Parameters" International Journal of Modern Engineering Research (IJMER), vol. 08, no. 10, 2018, pp 15-22