Research Article

Shashi Prakash Dwivedi* and Garima Dwivedi

Utilization of RHA in development of green composite material using RSM

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Abstract: In the present investigation, rice husk waste from rice mill was utilized in the development of aluminum based green metal matrix composite. Response surface methodology (RSM) was employed to develop green metal matrix composite by considering tensile strength as a response. Rice husk ash (RHA) was used as primary reinforcement material and B_4C was used as a secondary reinforcement material in the development of composite. Microstructure results showed a uniform distribution of RHA and B_4C in aluminum based matrix material. The optimum combination of reinforcement parameters was found to be RHA weight percentage of 7.8%, RHA preheats temperature of $231.12^\circ C$, B_4C preheats temperature of $435.24^\circ C$ and B_4C wt.% of 6.67% respectively to achieve a tensile strength of 249.867 MPa.

Keywords: RHA, Green Composite Material, B_4C , CCD, desirability

1 Introduction

The development of low density and low-cost metal matrix composite using waste material is one of the most interesting research areas in the current scenario. Nowadays; in all over the world, most of the researchers are focussing on green manufacturing research-based technology. Green manufacturing is the regeneration of a manufacturing route which provides a healthy environment condition or gives the technique so that the environment can keep green by minimizing the pollution [1, 2].

Aluminum alloys, due to having the automobile industry- relevant characteristics (such as lightweight, higher specific strength, higher specific stiffness), attracts

more and more researchers. Secondly, aluminum alloys show excellent improvement in its properties on being reinforced by some selected materials. Metal matrix composites (MMCs) are a combination of matrix and reinforcement [3–5]. Matrices can be selected from several Al alloy depending on the application like AA6061, AA2024, A356, etc. These aluminum alloys are most commonly used in automobile industries [6–12]. Further, it was observed that rice husk produces lots of soil pollution around rice mill area as shown in Figure 1.

Though various researchers tried to utilize RHA in various fields, but those techniques were costly and not friendly. In this study, RHA waste was utilized to develop a green metal matrix composite. In the present investigation, an attempt was made to utilize RHA as primary reinforcement material with B_4C as secondary reinforcement material in the development of Aluminium base composite using RSM.

Figure 1: Rice husk producing soil pollution

2 Materials and methods

2.1 Matrix material

In this study, Al 2024 is considered as a matrix material. AA2024 alloy is aluminum based alloy which has copper is

*Corresponding Author: Shashi Prakash Dwivedi: G. L. Bajaj Institute of Technology & Management, Greater Noida, Gautam Buddha Nagar, U.P. 201310, India; Email: spdglib@gmail.com

Garima Dwivedi: Kunwar Satya VIRA Group of Institutions, Bijnor., India

Table 1: Chemical Composition of AA2024 alloy [13]

Silicon	0.5%
Copper	3.8 – 4.9%
Manganese	0.3-0.9%
Iron	0.5%
Magnesium	1.2 – 1.8%
Chromium	0.10%
Zinc	0.25%
Ti	0.15%
Al	Balance

Table 2: Measured properties of AA2024 alloy

Melting point	580°C
Density (g/cm ³)	2.78
Tensile Strength (MPa)	180
Hardness (BHN)	48
Toughness (Joule)	11
Ductility (percentage elongation)	12

Figure 2: Burning temperature and duration of rice husk powder (RHP) to convert rice husk ash (RHA)

the main alloying element. Machining property of AA2024 alloy is average, while its corrosion resistance property is very low. It is very tough to weld. It is broadly used in aircraft industries in making wing and fuselage structures under simple tension due to its high fatigue and tensile strength. Its chemical compositions and mechanical properties are shown in Table 1 and Table 2 respectively.

2.2 Rice husk ash (RHA) as primary and B₄C as secondary reinforcement material

In the present study, agro waste rice husk ash (RHA) was utilized as reinforcement material in the development of green aluminum based metal matrix composites. Rice husk powder (RHP) was burned to obtain Rice husk ash (RHA) after ball milling as shown in Figure 2. Ceramic par-

Table 3: Comparative Study of Ceramic Particles and RHA Composition [14]

Compound	Cement (%)	RHA (%)
SiO ₂	20	94.8
CaO	63.2	1.41
Fe ₂ O ₃	3.3	1.61
K ₂ O	N.A.	1.33
TiO ₂	N.A.	0.17
MnO	N.A.	0.28
CuO	N.A.	0.04

Table 4: Properties of B₄C ceramic particles [15]

Property	Value
Density	2.52 g/cm ³
Crystal Structure	Rhombohedral
Melting Point	2450°C
Thermal Expansion Coefficient	$5 \times 10^{-4} \text{ } ^\circ\text{C}^{-1}$
Electrical Conductive	Electrical resistivity at 25°C is 0.1 – 10 ohm-cm

Table 5: Stir casting parameters for the development of composite

Casting Parameters	Parameter setting
Stirring Temperature	700°C
Blades speed (rotational speed of shaft in RPM)/ stirring speed	240
Time to hold/ stirring time	600 seconds
Blade angle	45°

Table 6: Process parameters with their ranges

S. No.	Input parameters	Range
1	RHA (wt.%)	2.5 – 12.5
2	RHA preheat temperature (Degree centigrade)	150 – 300
3	B ₄ C preheat temperature (Degree centigrade)	300 – 500
4	B ₄ C (wt.%)	2.5 – 12.5

ticle B₄C was used as a secondary reinforcement material. Table 3 shows the RHA composition used in this study.

2.3 Development of composite material

Stir casting technique was used to develop composite material. RHA and B₄C were utilized in the development of

Table 7: Design matrix and experimental results

Standard Order	Run	A: RHA (wt.%)	B: RHA preheat temperature (Degree centigrade)	C: B ₄ C preheat temperature (Degree centigrade)	D: B ₄ C (wt.%)	Tensile Strength (MPa)
24	1	7.50	225.00	400.00	17.50	239.4
19	2	7.50	75.00	400.00	7.50	244.6
21	3	7.50	225.00	200.00	7.50	243.3
9	4	2.50	150.00	300.00	12.50	232.2
25	5	7.50	225.00	400.00	7.50	249.25
2	6	12.50	150.00	300.00	2.50	245.8
23	7	7.50	225.00	400.00	0	248.1
3	8	2.50	300.00	300.00	2.50	243.3
17	9	0	225.00	400.00	7.50	231.2
13	10	2.50	150.00	500.00	12.50	242.2
12	11	12.50	300.00	300.00	12.50	242.5
16	12	12.50	300.00	500.00	12.50	239.2
29	13	7.50	225.00	400.00	7.50	249.5
10	14	12.50	150.00	300.00	12.50	241.2
27	15	7.50	225.00	400.00	7.50	249.4
4	16	12.50	300.00	300.00	2.50	248.4
18	17	17.50	225.00	400.00	7.50	238.2
15	18	2.50	300.00	500.00	12.50	240.8
7	19	2.50	300.00	500.00	2.50	245.2
8	20	12.50	300.00	500.00	2.50	243.4
26	21	7.50	225.00	400.00	7.50	249.35
22	22	7.50	225.00	600.00	7.50	248.4
30	23	7.50	225.00	400.00	7.50	248.8
14	24	12.50	150.00	500.00	12.50	244.3
11	25	2.50	300.00	300.00	12.50	238.3
20	26	7.50	375.00	400.00	7.50	246.2
28	27	7.50	225.00	400.00	7.50	248.9
5	28	2.50	150.00	500.00	2.50	244.85
1	29	2.50	150.00	300.00	2.50	236.5
6	30	12.50	150.00	500.00	2.50	247.8

composite material as reinforcement with the AA2024 aluminum alloy matrix. Reinforcement particles were added into melt material when the temperature of melt material was reached about 600°C as shown in Figure 3. Stir casting parameters for the development of hybrid composite materials are shown in Table 5. Table 6 shows the process parameters with their ranges. The design matrix table is shown in Table 7.

2.4 Response surface methodology

Response surface methodology (RSM) is defined as a collection of mathematical and statistical methods that are used to develop or optimize a product or process. The central composite design (CCD) was used to build a second order experimental model. CCD is composed of factorial points, a set of central points, and axial points equidistant to the center point. The factorial points are component of CCD of the class 2^k factorial, where k represents the number of appropriate factors or variables. The central point

Figure 3: Schematic diagram of a mechanical stir casting set-up [16]

Figure 4: Steps Involved in Central Composite Design

Figure 5: Microstructure of Al/RHA/B₄C hybrid metal matrix composite

component in the CCD is the average of the high and low values determined in the factorial points.

3 Results and discussion

3.1 Microstructure analysis

Microstructure image of green hybrid metal matrix composite reinforced with RHA and B₄C is shown in Figure 5. Microstructure image shows a uniform distribution of RHA

and B₄C in aluminum base matrix. This microstructure results showed that B₄C and RHA can be used simultaneously in the development of aluminum based hybrid metal matrix composite.

3.2 Mathematical modeling for development of green composites

ANOVA Table is indicated by Table 8 for mathematical modeling. From Table 8, it can be observed that the model term, as well as each independent input parameter, is significant. While “lack of fit” is insignificant. It was also observed from the ANOVA Table 8 that ceramic particle B₄C wt.% contributing most to enhance the tensile strength of composite followed by RHA wt.%, B₄C preheat temperature and RHA preheat temperature. Thus from the ANOVA Table, it can be concluded that the parameter, which one is contributing most to the tensile strength is B₄C wt.%. While the parameters which one is contributing least to the tensile strength is RHA preheat temperature. The tensile strength equation concerning input parameters is given below.

$$\begin{aligned} \text{Tensile Strength} = & +174.78698 + 4.53979 \times \text{RHA} \quad (1) \\ & + 0.20217 \times \text{RHA Preheat Temperature} \\ & + 0.15265 \times \text{B}_4\text{C Preheat Temperature} \\ & + 0.35146 \times \text{B}_4\text{C} - 0.14619 \times \text{RHA}^2 \\ & - 1.74167\text{E} - 004 \times \text{RHA} \\ & \text{Preheat Temperature} - 8.67187\text{E} - 005 \\ & \times \text{B}_4\text{C Preheat Temperature}^2 \\ & - 0.055687 \times \text{B}_4\text{C}^2 - 2.90833\text{E} - 003 \\ & \times \text{RHA} \times \text{RHA Preheat Temperature} \\ & - 3.24375\text{E} - 003 \times \text{RHA} \\ & \times \text{B}_4\text{C Preheat Temperature} \\ & - 4.62500\text{E} - 003 \times \text{RHA} \times \text{B}_4\text{C} \\ & - 2.27917\text{E} - 004 \\ & \times \text{RHA Preheat Temperature} \times \text{B}_4\text{C} \\ & \text{Preheat Temperature} - 7.41667\text{E} - 004 \\ & \times \text{RHA Preheat Temperature} \times \text{B}_4\text{C} \\ & + 6.31250\text{E} - 004 \times \text{B}_4\text{C} \\ & \text{Preheat Temperature} \times \text{B}_4\text{C} \end{aligned}$$

Figure 6 shows normal percent probability graph and predicted v/s actual graph. Both graphs are falling in straight line. Hence, all the experiments conducted for tensile strength is fair, arbitrary and randomly.

Table 8: ANOVA Table for Tensile strength

Source	Sum of square	DF	Mean square	F value	Prob. > F	
Model	734.0439	14	52.43171	917.8417	< 0.0001	significant
A	77.9401	1	77.9401	1364.378	< 0.0001	
B	3.720937	1	3.720937	65.13676	< 0.0001	
C	36.8776	1	36.8776	645.5598	< 0.0001	
D	112.4501	1	112.4501	1968.492	< 0.0001	
A ²	366.3563	1	366.3563	6413.24	< 0.0001	
B ²	26.3256	1	26.3256	460.8421	< 0.0001	
C ²	20.62667	1	20.62667	361.0796	< 0.0001	
D ²	53.16167	1	53.16167	930.6201	< 0.0001	
AB	19.03141	1	19.03141	333.1537	< 0.0001	
AC	42.08766	1	42.08766	736.7642	< 0.0001	
AD	0.213906	1	0.213906	3.74453	0.0721	
BC	46.75141	1	46.75141	818.4054	< 0.0001	
BD	1.237656	1	1.237656	21.66575	0.0003	
CD	1.593906	1	1.593906	27.90208	< 0.0001	
Residual	0.856875	15	0.057125			
Lack of Fit	0.451875	10	0.045187	0.55787	0.7979	not significant
Pure Error	0.405	5	0.081			
Cor Total	734.9008	29				
Std. dev.	0.24				R-Square	0.9988
Mean	243.68				Adj-R squared	0.9977
C.V.	0.098				Pred R-squared	0.9957
PRESS	3.16				Adeq precision	107.825

Figure 6: (a) Normal % probability graph, (b) predicted v/s actual graph

3.3 Process parameters effects on tensile strength

It was observed from the past analysis that very good mechanical properties can be obtained by considering the appropriate reinforcement parameters combination in the matrix material. Keeping these facts in the mind, various combinations of reinforcement parameters were taken by applying CCD (Central composite design) technique. By us-

ing CCD, an attempt was made to find out the appropriate combination of reinforcement parameters achieve maximum tensile strength.

Figure 7 (a) shows that by increasing the weight percentage of RHA up to center value, the tensile strength of hybrid composite increases, but beyond the center point tensile strength began to decreases. Figure 7 (b) displays that the tensile strength of hybrid green metal matrix composite also increases when RHA preheat temperature

Figure 7: Single reinforcement parameters effect on tensile strength

increases. Figures 7 (c) also show that tensile strength increases, when B_4C preheat temperature increases. Figure 7 (d) reveals that the tensile strength of composites decreases, when B_4C weight percentage increases.

Figure 8 (a–f) shows the three-dimensional (3D) interaction parameters effect on tensile strength of hybrid composite materials. It can be easily observed from Figures 7 (a) that when weight percent of RHA increases up to the center limit and RHA preheat temperature increases simultaneously then the tensile strength of composite also increases. In the same way, other interaction parameters effects can also be discussed.

Ramp function graph was plotted to obtain the optimum combination of reinforcement parameters to achieve maximum tensile strength. ramp function graph (Figure 9) shows that when RHA weight percentage, RHA preheat temperature, B_4C preheat temperature and B_4C wt.% are 7.8%, 231.12°C, 435.24°C and 6.67% respectively then the optimum value of tensile strength of the composite is 249.867 MPa with desirability one.

3.4 Mechanical properties of composite at optimum parameters

A confirmation experiment was carried out to see the effects of reinforcement addition on the mechanical properties of hybrid composites. Tensile strength was found to be 238.5 MPa at optimum parameters (RHA weight percentage of about 7.8%, RHA preheat temperature of about 231.12°C, B_4C preheat temperature of about 435.24°C and B_4C wt.% of about 6.67%). Tensile strength results showed that there is only a 4.4% error in the developed model and experimental result. However, hardness was also increased by about 35.41%. Though, toughness and ductility were reduced with respect to the base metal as shown in Figure 10.

3.5 Corrosion behaviour of hybrid composite at optimum reinforcement parameters

Corrosion test of all the samples was carried out to identify the durability (life) of developed composite materials concerning surrounding moisture and environment. The corrosion test of all the samples was carried out in 3.5 wt.% NaCl for 120 hours. The weight of each sample was taken 9 gm to make uniformity for the corrosion test. Corrosion be-

Figure 8: 3D reinforcement parameters effect on tensile strength

Figure 9: Ramp function graph

Figure 10: Mechanical Properties at optimum Reinforcement Parameters

Figure 11: Corrosion behavior of hybrid composite at optimum reinforcement parameters

haviour of a hybrid composite at developed at optimum reinforcement parameters (RHA weight percentage of about 7.8%, RHA preheat temperature of about 231.12°C, B₄C preheat temperature of about 435.24°C and B₄C wt.% of about 6.67%) was investigated. Weight loss of hybrid composite after the corrosion test was found to be 8.98 mg. There was only 0.02 mg material of hybrid composite was corroded as shown in Figure 11.

3.6 Thermal expansion behavior of hybrid composite at optimum reinforcement parameters

The thermal expansion property of each green composite material was identified to observe the appropriateness of material in a high-temperature environment. Dimension (Volume: 2700 mm³ (27 × 10 × 10)) of each sample was kept constant. The thermal expansion of all prepared samples was carried out in muffle furnace at 450°C constant temperature for 48 hours. The thermal expansion behaviour of the hybrid composite at optimum reinforcement parameters was investigated as shown in Figure 12. The volume

Figure 12: Thermal expansion behavior of hybrid composite at optimum reinforcement parameters

of the hybrid composite after the thermal expansion was found to be 2680 mm³, which is acceptable.

4 Conclusions

The following conclusions can be drawn from the analysis.

1. Soil pollution can be reduced by using rice husk ash as reinforcement material in the development of green composite material.
2. Al2024 aluminum alloy is one of the most demanding materials in automobile industries due to its light weight and good strength.
3. Green metal matrix composite with RHA and B₄C as reinforcement materials and Aluminium as matrix material can be successfully developed using a stir casting technique.
4. Microstructure results showed a uniform distribution of B₄C and RHA in Al2024 based matrix material.
5. The optimum combination of reinforcement parameters was found to be RHA weight percentage of 7.8%, RHA preheat temperature of 231.12°C, B₄C preheat temperature of 435.24°C and B₄C wt.% of 6.67%, respectively to achieve the tensile strength of 249.867 MPa with desirability one.
6. The mechanical properties of hybrid composites were investigated at optimum reinforcement parameters. Mechanical properties were enhanced significantly at optimum reinforcement parameters.
7. Corrosion loss and thermal expansion results showed that material is stable in a moisture environment and high-temperature surrounding.

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