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Utilization of RHA in development of hybrid composite by electromagnetic stir casting technique using RSM

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Abstract

In the present investigation, hybrid metal matrix composite was developed using electromagnetic stir casting technique. AA2024 alloy was used as matrix material. RHA (rice husk ash) was used as primary reinforcement material, while B_4C (boron carbide) was used as secondary reinforcement material. CCD (central composite design) was employed to develop design matrix table for fabrication of hybrid composite by electromagnetic stir casting technique. Microstructure result showed uniform distribution of RHA and B_4C in matrix material. Ramp function graph showed that when RHA preheat temperature, RHA weight percentage, Electromagnetic stirring time, B_4C preheat temperature and B_4C wt.% are 272.57°C, 12.5%, 180 s, 312.38°C and 12.5% respectively then the optimum value of tensile strength of composite was found to be 258.498 MPa with desirability 0.958. Hardness, toughness and ductility were also observed at optimum electromagnetic stir casting parameters.

1. Introduction

There are various types of reinforcements used in development of aluminium based metal matrix composite. It was observed that by using ceramic particles, mechanical properties such as hardness and tensile strength were improved. However, density and cost were also increased [1-3]. Rice husk ash is waste products which produce lots of soil pollution as shown in Figure 1. Green production is a business strategy that emphasis on profitability through environmentally friendly operating process. Rice husk ash is an aviculture by product that has been listed worldwide as one of the worst environmental problems. By utilizing Rice husk ash as reinforcement material with aluminium, mechanical properties can be improved. Further, density and cost of composite can be reduced [4-5].

Figure 1. Rice husk producing soil and air pollution [16].

Nowadays, aluminium based metal matrix composite are used in various industrial application where good mechanical properties are required. However, various ceramic particles were used in development of composite and improved mechanical properties. But, it's overall density also increased [6-8].

Rice husk is an abundantly available agricultural waste material that contains a large amount of siliceous ash. The previous research data suggests that 70 million tons of RHA is generated per annum worldwide, which is sent to dump yards or burned. The dumping and/or burning of RHA pose serious environmental threats to surrounding regions. Burning rice husk in air produces RHA, which is 85-98% silica. Burnt rice husk causes environmental pollution and poses a health hazard. Further, Rice-husk disposal can be costly. Usually, RHA dust mixed with air causes respiratory issues through clogging of lungs when individuals inhale them. Adding to this, it affects the eyes as well [9-11].

In the present study, rice husk ash is used as primary reinforcement material. B_4C was used as secondary reinforcement material in the development of composites by electromagnetic stir casting process. It was also observed that mechanical properties of composites depend on various parameters such as reinforcement preheat temperature, reinforcement weight percentage in matrix, type of casting and its parameters. Keeping these facts in the mind, in the present investigation, combined effects of reinforcement parameters and casting parameters effect on tensile strength of composites were evaluated using response surface methodology.

2. Experimental

2.1 Matrix material

In this study, Al 2024 is considered as matrix material. AA2024 alloy is aluminium based alloy which has copper is the main alloying element. Machining property of AA2024 alloy is average, while

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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 structure 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.

Table 1. Chemical composition of AA2024 Alloy.

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%
Titanium	0.15 %
Aluminium	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

2.2 Rice Husk Ash (RHA) as primary and B_4C as secondary reinforcement material.

In the present study, agro waste rice husk ash (RHA) was utilized as reinforcement material in the development of green aluminium based metal matrix composites. Rice husk powder was collected from rice mill industry. It does not burn easily with an open flame, unless air is blown through the husk. RHA (Rice husk ash) is obtained after carbonizing process of RHP (Rice husk powder). Its disposal also evokes environmental problems because RHA does not biodegrade easily and it generates pollution, which has caused health problems to the inhabitants. In Uruguay, RHA was thrown into the river and brought about great contamination and ecological concern. By, utilizing this RHA in development of composite material, some environmental problem such as soil pollution can be reduced. Keeping these facts in the mind, in this study, waste RHA is used as primary reinforcement material. Theoretical density of RHA was 1.60 g·cm^{-3} respectively. Chemical composition of RHA is shown in Table 3. Compositions of RHA show the presence of SiO_2, CaO, Fe_2O_3, K_2O, TiO_2, MnO and CuO phases [10,11]. Presence of these phases may be the responsible for increasing the mechanical properties of aluminium based composite. When rice-husk powder is burnt, rice-husk ash (RHA) is generated. On burning, cellulose and lignin are removed leaving behind silica ash. The controlled temperature and environment of burning yields better quality of rice-husk ash as its particle size and specific surface area are dependent on burning condition. Rice husk powder (RHP) was burned to obtain Rice husk ash (RHA) after ball milling as shown in Figure 2. First of all, rice husk powder (RHP) was kept in furnace. Rice-husk powder was burnt in a controlled atmosphere in the laboratory. Temperature of furnace was increased slowly up-to 500°C. Temperature of the furnace was recorded each one hour of interval as shown in Figure 2. It can be observed that temperature of 500°C of furnace (in which rice husk powder was burning) was achieved after 15 h. When temperature of furnace reached to 500°C, temperature of furnace was set to cool slowly. Whole process was carried out for 34 h to obtain RHA (rice husk ash).

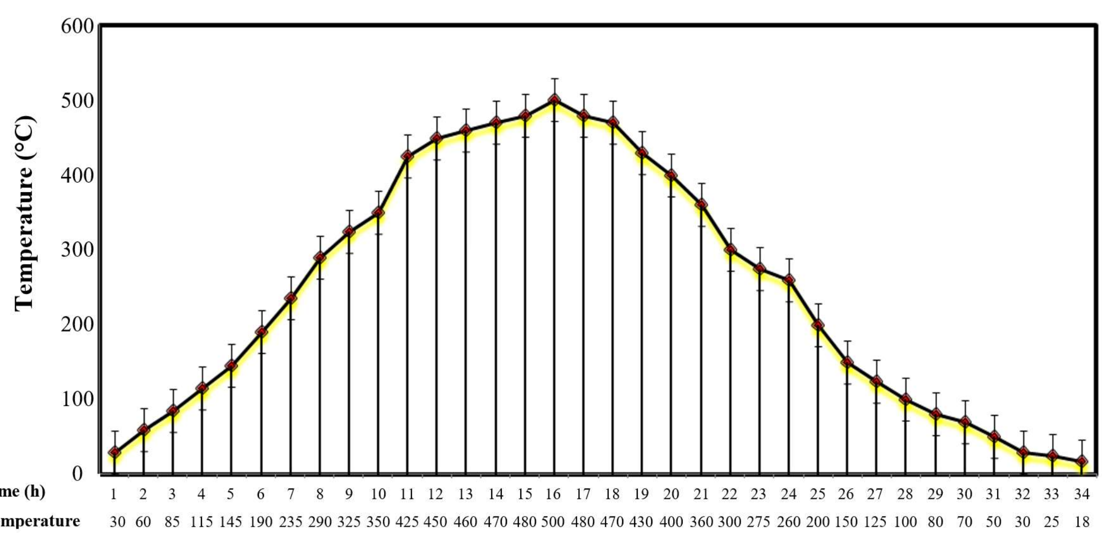

Figure 2. Burning temperature and duration of rice husk powder (RHP) to convert rice husk ash (RHA).

Table 3. Composition of RHA [10,11].

Compound	RHA (%)
SiO_2	94.8
CaO	1.41
Fe_2O_3	1.61
K_2O	1.33
TiO_2	0.17
MnO	0.28
CuO	0.04

In the present investigation, ceramic particle B_4C was used as secondary reinforcement material. Boron Carbide (B_4C) is one of the hardest materials known, ranking third behind diamond and cubic boron nitride. It is the hardest material produced in tonnage quantities. Keeping these facts in the mind, in this study, Boron Carbide (B_4C) is used as secondary reinforcement material to increase further mechanical properties of Al/RHA composite. Table 4 shows the properties of Boron Carbide (B_4C). Boron carbide was first synthesized by Henri Moissan in 1899, by reduction of boron trioxide either with carbon or magnesium in presence of carbon in an electric arc furnace [14]. In the case of carbon, the reaction occurs at temperatures above the melting point of B_4C and is accompanied by liberation of large amount of carbon monoxide:

Table 4. Properties of boron carbide [12,13].

Parameters	Values
Density ($g \cdot cm^{-3}$)	2.52
Melting Point (°C)	2445
Hardness (Knoop 100 g) ($kg \cdot mm^{-2}$)	2900-3580
Fracture Toughness ($MPa \cdot m^{-½}$)	2.9-3.7
Young's Modulus (GPa)	450-470
Electrical Conductivity (at 25°C) (S)	140
Thermal Conductivity (at 25°C) ($W \cdot m^{-1}K^{-1}$)	30-42

2.3 Development of composite material by electromagnetic stir casting process.

Figure 3 shows the schematic diagram of electromagnetic stirring set up. Electromagnetic stir casting set-up was developed to process the hybrid composite material. Firstly, Aluminium was cleaned and loaded in the graphite crucible and heated to above its liquidus temperature in muffle furnace. When temperature of melt aluminium alloy was reached to 700°C, the liquid aluminum alloy at a given temperature was poured into the graphite crucible which was packed very well with the help of glass wool (thermal insulator) to prevent the heat transfer of melt aluminium alloy to motor coil. RHA was used as primary reinforcement material and B_4C was utilized as secondary reinforcement material in development of composite material. Preheated RHA and B_4C particles were added in matrix material as per the design matrix Table 4. Developed hybrid composite material was allowed to cool inside the graphite crucible for half an hour. The prepared samples were removed from the crucible after solidification.

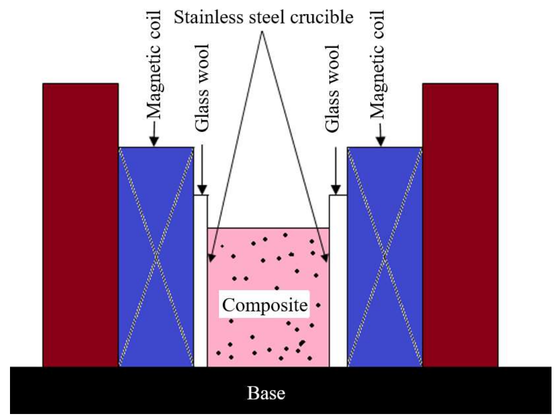

Figure 3. Schematic diagram of electromagnetic stir casting set-up.

2.4 Selection of electromagnetic stir casting and reinforcement parameters

For the selection of electromagnetic stir casting parameters and reinforcement parameters (RHA preheat temperature, Weight percentage of RHA, Electromagnetic Stirring Time, B_4C preheat temperature, Weight percent of B_4C), numerous experiments were carried out. In the pilot run, arbitrarily the weight percent of RHA was chosen 1.5% for the fabrication of aluminium based hybrid composite and others parameters such as RHA preheat temperature, Electromagnetic Stirring Time, B_4C preheat temperature, Weight percent of B_4C were kept constant. It was found that the mechanical properties were not significantly improved. When, RHA weight percent increased by 2.5%, some mechanical properties improved. Further, RHA was increased to 15%, it was observed that the mechanical properties of hybrid composite were improved (but not significantly improved). Hence, After the pilot run investigation, RHA weight percent was chosen in the range of 2.5% to 12.5%. Same course of action was conducted to decide the ranges for other parameters. Reinforcement parameters with their ranges on pilot run investigation are shown in Table 5.

In the present investigation, central composite design (CCD) was used to obtain optimum electromagnetic and reinforcement parameters for maximum mechanical properties. It was observed some experiments that response was obtained sometimes better beyond the chosen input parameters range. Hence, CCD is always checked the response value beyond the input range parameters. Hence, for each parameter it can be observed that one run is below the chosen range of parameter, and one run is above the chosen parameter range. For example, range of B_4C preheat temperature is 300-500 degree centigrade. But, one run is carried out at 217.884 degree centigrade, and another run is carried out at 582.116 degree centigrade. Same course of action was conducted to decide the ranges for other parameters. Input parameters were selected randomly as per design matrix shown in Table 6 and corresponding measured tensile strengths of hybrid composite material under different runs are also given in Table 6.

Table 5. Process parameters with their ranges.

S. No.	Input parameters	Range
1	RHA preheat temperature (Degree centigrade)	200 - 400
2	RHA (wt. %)	2.5 - 12.5
3	Electromagnetic Stirring Time (Sec)	6- 180
4	B4C preheat temperature (Degree centigrade)	300 - 500
5	B4C (wt. %)	2.5 - 12.5

Table 6. Design matrix and experimental results.

Standard order	Run	A: RHA preheat temperature (degree centigrade)	B: RHA (wt%)	C: Electromagnetic stirring time	D: B_4C preheat temperature (degree centigrade)	E: B_4C (wt%)	Tensile strength (MPa)
25	1	300	7.5	120	400	7.5	235.75
19	2	300	7.5	120	582.116	7.5	225.6
15	3	300	16.6058	120	400	7.5	240
1	4	400	12.5	60	500	2.5	207.5
20	5	300	7.5	120	400	0	201.3
17	6	300	7.5	229.2696	400	7.5	243.2
24	7	300	7.5	120	400	7.5	235.7
14	8	300	0	120	400	7.5	235
16	9	300	7.5	10.73038	400	7.5	233.8
4	10	400	12.5	180	300	2.5	217.5
5	11	400	12.5	60	300	12.5	256
26	12	300	7.5	120	400	7.5	235.25
22	13	300	7.5	120	400	7.5	235.6
18	14	300	7.5	120	217.884	7.5	237.5
8	15	200	12.5	60	500	12.5	244
21	16	300	7.5	120	400	16.6058	261
12	17	117.884	7.5	120	400	7.5	217
2	18	400	2.5	180	500	2.5	208
23	19	300	7.5	120	400	7.5	235.4
3	20	200	12.5	180	300	12.5	255
6	21	400	2.5	60	500	12.5	245
11	22	200	2.5	60	300	2.5	201
9	23	400	2.5	180	300	12.5	255
13	24	482.116	7.5	120	400	7.5	224
10	25	200	12.5	180	500	2.5	219
7	26	200	2.5	180	500	12.5	247
25	1	300	7.5	120	400	7.5	235.75
19	2	300	7.5	120	582.116	7.5	225.6
15	3	300	16.6058	120	400	7.5	240
1	4	400	12.5	60	500	2.5	207.5

2.5 Response Surface Methodology (RSM)

Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building. By careful design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables). An experiment is a series of tests, called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response. An important aspect of RSM is the design of experiments (Box and Draper, 1987), usually abbreviated as DoE. These strategies were originally developed for the model fitting of physical experiments, but can also be applied to numerical experiments. The objective of DoE is the selection of the points where the response should be evaluated.

A second-order model can be constructed efficiently with central composite designs (CCD) (Montgomery, 1997). CCD is first-order (2 N) designs augmented by additional centre and axial points to allow estimation of the tuning parameters of a second-order model. Figure 4 shows a CCD for 3 design variables. In Figure 4, the design involves 2 N factorial points, 2N axial points and 1 central point. CCD presents an alternative to 3N designs in the construction of second-order models because the number of experiments is reduced as compared to a full factorial design (15 in the case of CCD compared to 27 for a full-factorial design). CCD has been used by Eschenauer and Mistree (1997) for the multiobjective design of a flywheel. However, In the case of problems with a large number of designs variables, the experiments may be time-consuming even with the use of CCD

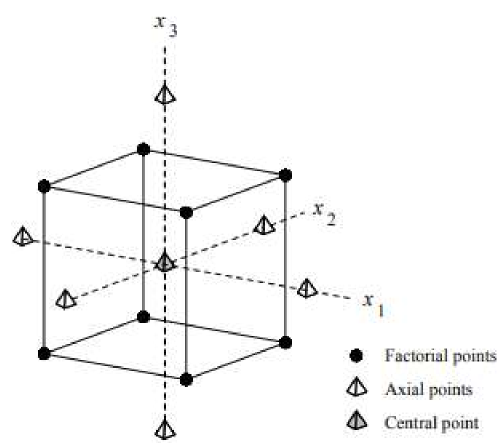

Figure 4. Central composite design for 3 design variables at 2 levels.

3. Results and discussion

3.1 Microstructure analysis

Figure 5 shows the microstructure image of hybrid composite material. Microstructure image was observed at the optimum parameters of electromagnetic stir casting process. Microstructure image shows uniform distribution at optimum parameter of electromagnetic stir casting process as shown in Figure 5 (a). However, some agglomeration of RHA reinforcement was observed during casting of hybrid composite material beyond the range of process parameters as shown in Figure 5 (b). Rice husk ash (RHA) was obtained after carbonizing the rice husk powder. After carbonizing process, rice husk ash is obtained in form of ash. These ashes are usually obtained in form of uneven shape. While, Boron carbide (B_4C) was collected directly from shop in form of ceramic powder. This Boron carbide (B_4C) was further ball milled to obtain uniform shape. Hence, from the microstructure, it may be observed that particle size of Boron carbide (B_4C) is less than particle size of RHA.

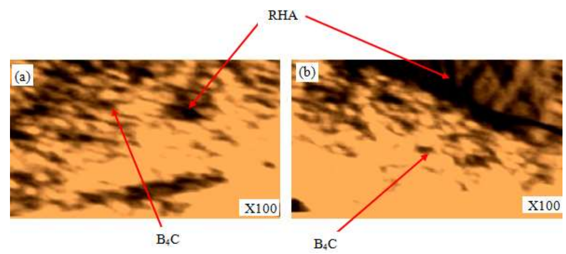

Figure 5. Microstructure of Al/RHA/B_4C hybrid composite material (a) developed at optimum parameter of electromagnetic stir casting process, (b) developed at beyond the range of process parameters.

3.2 Mathematical Modeling for Development of Green Composites

ANOVA Table is indicated by Table 7 for mathematical modeling. The Model F-value of 4328.76 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, D, E, A^2, B^2, C^2, D^2, E^2, AB, AC, AD, AE, BC, BE, CD, DE are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The "Lack of Fit F-value" of 5.24 implies there is a 8.39% chance that a "Lack of Fit F- value" this large could occur due to noise. Lack of fit is bad -- we want the model to fit. Tensile strength equation with respect to input parameters is given in equation 1.

$$\text{Tensile Strength} = +\ 72.30 + 0.55A + 2.12\times B + 0.27\times C + 0.18\times D + 2.40\times E - 4.59\times10^{-4}\times A^2 + 0.02\times B^2 + 2.31\times10^{-4}\times C^2 - 1.26\times10^{-4}\times D2 - 0.06\times E^2 - 5.91\times10^{-3}\times A\times B - 7.15\times10^{-4}\times A\times C - 3.44\times10^{-4}\times A\times D + 1.55\times10^{-3}\times A\times E - 3.30\times10^{-3}\times B\times C - 7.85\times10^{-4}\times B\times D + 0.04\times B\times E - 1.21\times10^{-4}\times C\times D + 1.22\times10^{-3}\times C\times E + 1.93\times10^{-3}\times D\times E \quad (1)$$

Table 7. ANOVA Table for Tensile strength.

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	7082.274821	20	354.1137411	4328.7551	< 0.0001	significant
A	24.5	1	24.5	299.492755	< 0.0001	
B	12.5	1	12.5	152.802426	< 0.0001	
C	44.18	1	44.18	540.064894	< 0.0001	
D	70.805	1	70.805	865.534062	< 0.0001	
E	1782.045	1	1782.045	21784.0639	< 0.0001	
A^2	437.492024	1	437.492024	5347.98741	< 0.0001	
B^2	5.848386893	1	5.848386893	71.4918164	0.0004	
C^2	14.37145755	1	14.37145755	175.679486	< 0.0001	
D^2	33.04852907	1	33.04852907	403.991633	< 0.0001	
E^2	39.66273434	1	39.66273434	484.844962	< 0.0001	
AB	26.71155253	1	26.71155253	326.527202	< 0.0001	
AC	56.23054441	1	56.23054441	687.373088	< 0.0001	
AD	36.19674392	1	36.19674392	442.476023	< 0.0001	
AE	1.839060473	1	1.839060473	22.4810321	0.0051	
BC	2.99716333	1	2.99716333	36.6379062	0.0018	
BD	0.470528277	1	0.470528277	5.75182897	0.0618	
BE	3.530662142	1	3.530662142	43.1594992	0.0012	
CD	1.608169984	1	1.608169984	19.658582	0.0068	
CE	0.411197331	1	0.411197331	5.02655598	0.0750	
DE	2.844376026	1	2.844376026	34.7702046	0.0020	
Residual	0.40902492	5	0.081804984			
Lack of Fit	0.23202492	1	0.23202492	5.24350101	0.0839	not significant
Pure Error	0.177	4	0.04425			
Cor Total	7082.683846	25				
Std. Dev.	0.286016	R-Squared	0.99994225			
Mean	232.7346	Adj R-Squared	0.99971125			
C.V.	0.122893	Pred R-Squared	0.976355386			
PRESS	167.4673	Adeq Precision	232.4501417			

The "Pred R-Squared" of 0.9764 is in reasonable agreement with the "Adj R-Squared" of 0.9997. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 232.450 indicates an adequate signal. This model can be used to navigate the design space. Diagnostics case statistics Table (Table 8) shows that all the experiments conducted for tensile strength is fair, arbitrary and randomly

3.3 Electromagnetic stir casting process parameters effects on tensile strength

It was observed from previous research work that excellent mechanical properties can be obtained by considering the suitable reinforcement parameters combination in development of composite material. In this study, an attempt was made to find out appropriate combination of reinforcement parameters to achieve maximum tensile strength by using central composite design (CCD).

Figure 6 shows the effects of electromagnetic stir casting parameters on tensile strength of hybrid composite material. It can be observed from the analysis that tensile strength increases by increasing the RHA preheat temperature up to center limit. However, tensile strength began to decrease beyond the center limit of RHA preheat temperature. Tensile strength increases by increasing the RHA weight percentage, stirring time and Boron Carbide weight percentage as shown in Figure 6. However, tensile strength of hybrid composite began to decrease by increasing the Boron Carbide preheat temperature beyond 312.38°C.

Ramp function graph was plotted to obtain optimum combination of electromagnetic stir casting parameters to achieve maximum tensile strength. Ramp function graph (Figure 7) shows that when RHA preheat temperature, RHA weight percentage, Electromagnetic stirring time, B_4C preheat temperature and B_4C wt.% are 272.57˚C, 12.5%, 180 sec, 312.38˚C and 12.5% respectively then the optimum value of tensile strength of composite was found to be 258.498 MPa with desirability 0.958.

3.4 Mechanical properties of composite at optimum parameters

Confirmation experiment was carried out to see the effects of electromagnetic stir casting parameter effects on mechanical properties of hybrid metal matrix composites. Figure 8(a) shows the comparative experimental tensile strength value of hybrid composite material developed at optimum parameters and matrix material. Tensile strength was found to be 246.5 MPa at optimum parameters (RHA preheat temperature of about 272.57°C, RHA weight percentage of 12.5%, Stirring time of 180 sec, B_4C preheat temperature of about 312.38°C and B_4C wt.% of 12.5%). Tensile strength results showed that there is only 4.6% error in developed model and experimental result (Figure 8 (b)). However, hardness was also increased about 39.58%. Though, toughness and ductility were reduced with respect to AA2024 alloy as shown in Figure 8 (c) and (d).

Table 8. Diagnostics case statistics

Standard order	Actual value	Predicted value
1	207.5	207.56
2	208	208.065
3	255	255.065
4	217.5	217.56
5	256	256.06
6	245	245.06
7	247	247.06
8	244	244.06
9	255	255.06
10	219	219.06
11	201	201.13
12	217	216.88
13	224	223.88
14	235	234.88
15	240	239.88
16	233.8	233.68
17	243.2	243.08
18	237.5	237.38
19	225.6	225.48
20	201.3	201.18
21	261	260.88
22	235.6	235.61
23	235.4	235.61
24	235.7	235.61
25	235.75	235.61
26	235.25	235.61

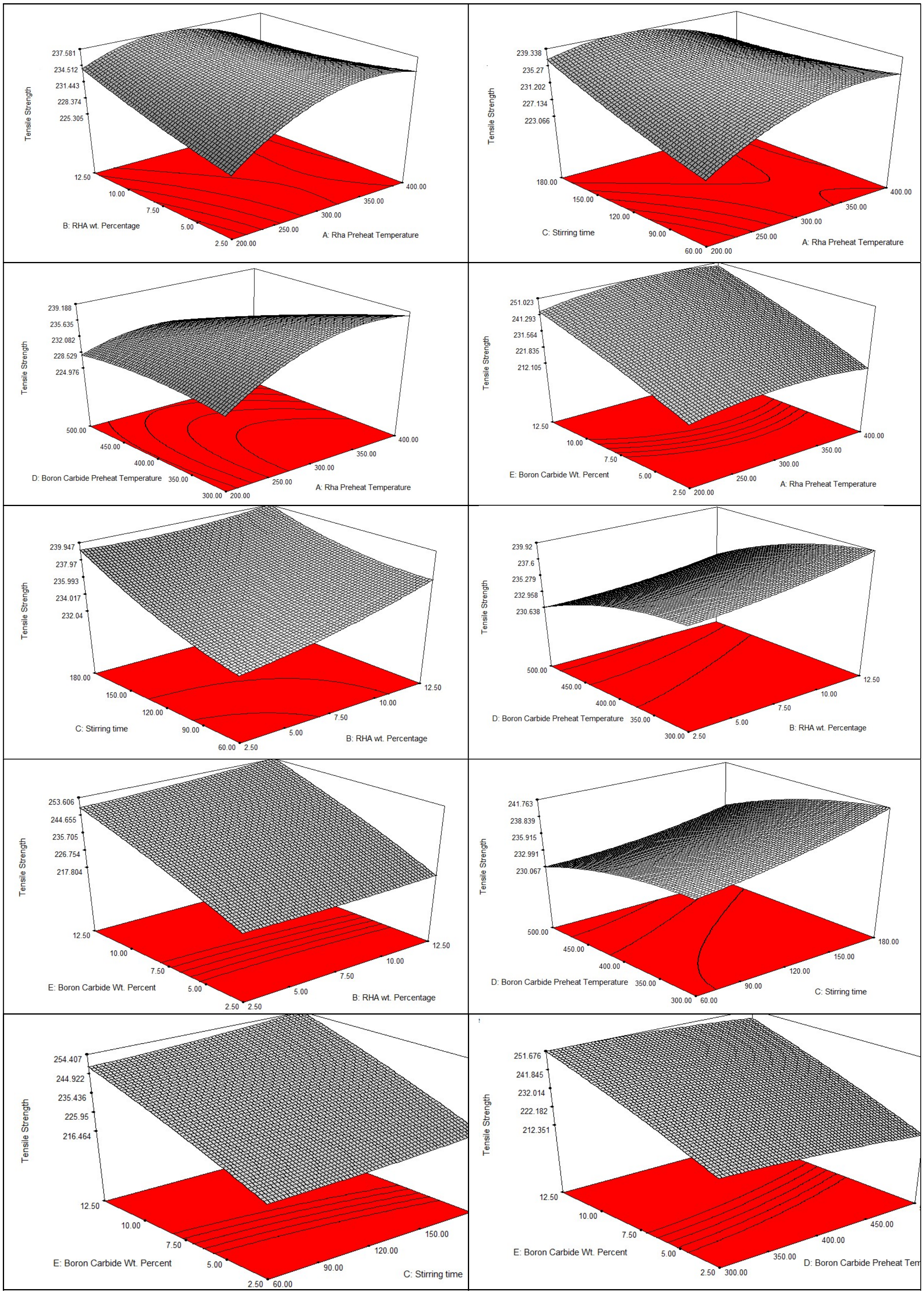

Figure 6. 3D reinforcement parameters effect on tensile strength.

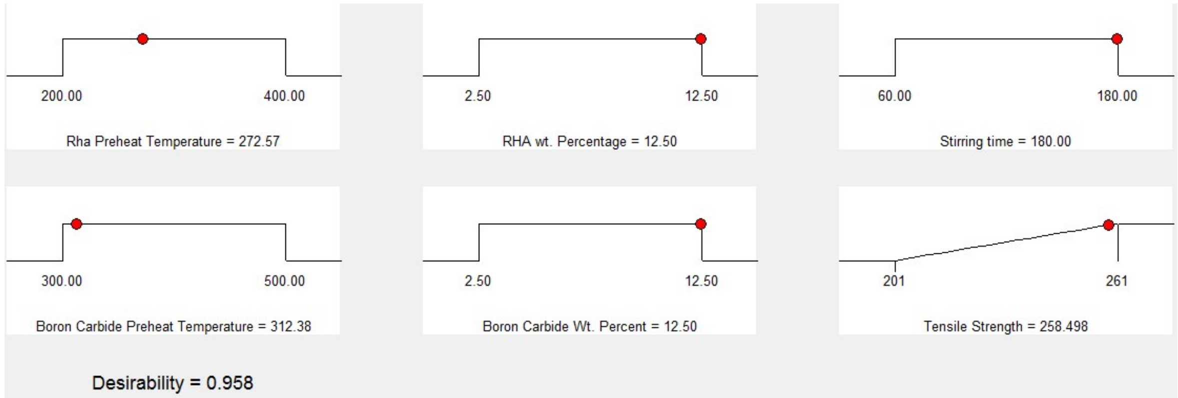

Figure 7. Ramp function graph.

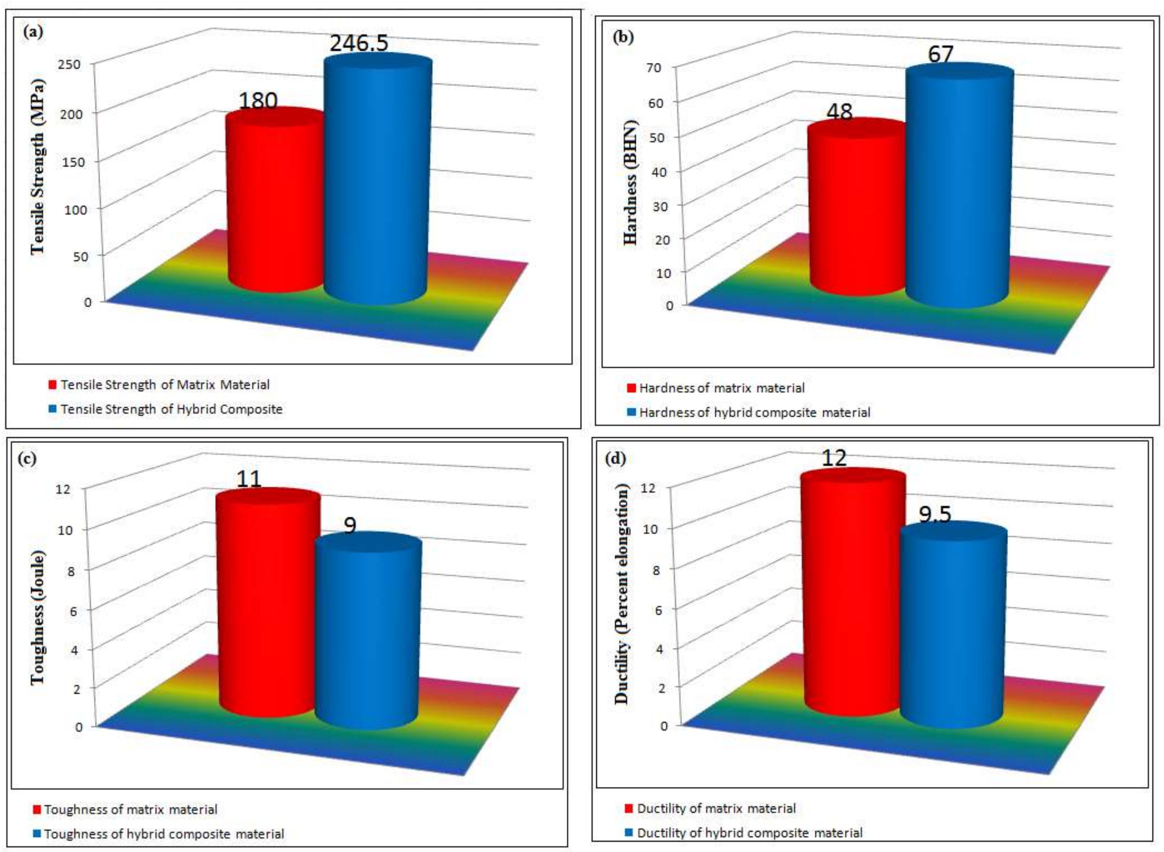

Figure 8. Mechanical properties at optimum reinforcement parameters.

4. Conclusion

The following conclusions can be drawn from the analysis.

1. Soil pollution can be reduced by using rice husk ash as reinforcement material in development of green composite material.
2. Green metal matrix composite with RHA and B_4C as reinforcement materials and Aluminium as matrix material can be successfully developed using electromagnetic stir casting technique.
3. Microstructure results obtained at optimum parameters of electromagnetic stir casting showed uniform distribution of B_4C and RHA in Al2024 based matrix material.
4. Optimum combination of electromagnetic stir casting parameters were found to be RHA preheat temperature of about 272.57°C, RHA weight percentage of 12.5%, Stirring time of 180 sec, B_4C preheat temperature of about 312.38°C and B_4C wt. % of 12.5% to achieve tensile strength of 258.5 MPa with desirability 0.958.

5. Mechanical properties of hybrid composites were investigated at optimum reinforcement parameters. Tensile strength and hardness were enhanced significantly at optimum electromagnetic stir casting parameters. However, toughness and ductility were reduced.

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