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TECHNICAL NOTE - MECHANICAL ENGINEERING

Physico-Chemical, Mechanical and Thermal Behaviour of Agro-waste RHA-Reinforced Green Emerging Composite Material

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Abstract

Ceramic particles such as SiC, Al_2O_3 and B_4C are most commonly used as reinforcement particles while developing composite materials. The industries producing these particles emit huge amount of greenhouse gases such as N_2O_3, CH_4 and CO_2. Emission of these gases poses serious threats to the neighbouring environment. Adding to environmental concerns, the costs of production for ceramic particles are very high. The present study has used rice husk ash (RHA) as a partial replacement of ceramic particles. Microstructural examinations have shown evidence of RHA particles in the aluminium-based metal matrix composite samples. It was also revealed that tensile strength and hardness increased about 48% and 48.33% with respect to base metal (AA6063), after mixing the carbonized RHA into matrix material. Presence of SiO_2, CaO, Fe_2O_3 compositions in carbonized RHA improves the tensile strength and hardness of composites. Porosity of Al/7.5 wt% carbonized RHA metal matrix composite was found to be 6.33%, which is acceptable. Maximum specific strength and minimum corrosion loss were found to be 65.57 kN m/Kg (for 8.75 wt% of carbonized reinforced RHA) and 0.17 mg (for 5 wt% of carbonized reinforced RHA), respectively. Density and cost of RHA-reinforced composite continuously decrease with the increase in percentage of reinforcement. Minimum thermal expansion (50.98 mm^3) was observed for 6.25 wt% of carbonized RHA-reinforced composite. It was also observed from the analysis that carbonized RHA-reinforced composite provides better result as compared to uncarbonized RHA-reinforced composite.

Keywords Agro-waste · RHA · Green composite materials · Mechanical properties · Corrosion · Thermal expansion

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 present scenario. Nowadays, most of the researchers across the world are focused towards the green manufacturing technology. Green manufacturing is the regeneration of manufacturing route which provides healthy environmental conditions. Further, most of the research work is carried out in manufacturing using various recycled wastes, especially in the development of metal matrix composite [1–10]. The recycled waste products are rice husk ash, fly ash, red mud, waste eggshell ash, bagasse ash etc. Among them, rice husk ash (RHA) is an agriculture by-product and easily available. The previous research data suggest 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. 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 [11,12].

Rattanasak et al. [13] used high volume of rice husk ash (RHA) as reinforcement material to develop alumino silicate composites (ASC). Results have shown that ASC were not stable and disintegrated with water. To overcome this problem, boric acid was introduced in the mixture of alumino silicate composites. Dinaharan et al. [14] developed RHA-reinforced aluminium-based composite by using friction stir process technique. An improvement was observed in tensile strength of aluminium-based composite. Dinaharan et al. [15] prepared copper-based composite by using RHA as reinforcement by friction stir process. Wear behaviour of composite was observed. Wear resistance of copper-based

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composites improved after using RHA as reinforcement material. Gladston et al. [16] also observed wear behaviour of AA6061/RHA metal matrix composites. Results showed that RHA particles refined the grains of the aluminium matrix; as a result wear resistance of the composite was improved. Alaneme et al. [17] fabricated aluminium-based hybrid metal matrix composite by using RHA as primary reinforcement material and SiC as secondary reinforcement material. Corrosion behaviour of hybrid composite material was identified in H_2SO_4 and NaCl solutions. Corrosion resistance improved after using the RHA as primary reinforcement material. Verma et al. [18] investigated the mechanical behaviour of AA7075-B_4C-rice husk ash (RHA) hybrid composite. Mechanical testing has shown improvement in the hardness and tensile strength of hybrid composite by using RHA as reinforcement with B_4C in AA7075 alloy. Alaneme et al. [19] utilized RHA, alumina and graphite as reinforcement material with different weight proportions in aluminium base matrix material. Microstructural characteristics, mechanical and wear behaviour of hybrid composites were analysed. Results showed that hybrid composites without graphite exhibited greater wear susceptibility in comparison with the composite grades containing graphite. However, the wear resistance decreased with the increase in the graphite content from 0.5 to 1.5 wt%. Kingsly Gladston et al. [20] produced rice husk ash particulate-reinforced AA6061 aluminium alloy composites by compo-casting technique. Good bonding was observed at the interfaces of aluminium and RHA. Further, the reinforcement of RHA particles enhanced the microhardness and ultimate tensile strength (UTS) of the composite. Deshmukh et al. [21] extracted SiO_2 from agro-waste RHA in development of composite. Experimental results of the synthesized composite showed the presence of $MgAl_2O_4$ (spinel structure) and other phases like MgO and Mg_2Si which impart hardness of composites. Saravanan et al. [22] utilized rice husk ash (RHA) as reinforcement in aluminium-based composite to predict the wear rate and coefficient of friction. Vinod et al. [23] developed RHA and fly ash-reinforced aluminium-based composite material to observe tribological behaviour of hybrid composite. The results revealed that the A356/10% RHA-10% fly ash hybrid composite exhibited superior wear resistance compared with the aluminium matrix.

However, in previously published work of the author [24–31], effective utilization of eggshell waste in the development of aluminium-based composite material was discussed. Results showed that by using the eggshell as reinforcement material, mechanical properties were improved. While, corrosion resistance, thermal expansion and density of eggshell-reinforced composite material were reduced significantly.

It was observed from the literature that various researchers used RHA as reinforcement material to develop aluminium-based metal matrix composite. It was also observed that, by using RHA as reinforcement material in aluminium base matrix, tensile strength and hardness improved significantly. Apart from mechanical properties, factors such as corrosion loss, thermal expansion, porosity, density and cost of materials play significant role in selection of material and manufacturing processes.

It is evident from the literature review that only handful of researchers discussed about thermal behaviour, porosity, cost and corrosion behaviour of RHA-reinforced aluminium-based composite. However, in previously published work of the author [24–31], thermal behaviour, corrosion loss, cost and porosity of composite material were discussed. In the case of aforesaid work, eggshell reinforcement material was used with aluminium. Keeping these facts in mind, along with tensile strength and hardness, other important properties like corrosion loss, thermal expansion, density, porosity and cost have been observed in the present work.

2 Materials and Methods

2.1 Matrix Material

In the present investigation, Al6063 is considered as matrix material. AA6063 aluminium alloy is used in the application of architectural field. This alloy is also known as medium strength alloy. AA6063 alloy can also be used in automobile sector after making its composite by using appropriate reinforcement. It has a superior corrosion resistance and surface finish. Tables 1 and 2 show the chemical composition and mechanical properties of AA6063 alloy. However, tensile strength and hardness of AA6063 alloy was measured to identify actual property of alloy.

Table 1 Chemical composition of AA6063 alloy [32]

Silicon	0.25%
Copper	0.10%
Manganese	0.10%
Iron	0.35%
Magnesium	0.45%
Chromium	0.10%
Zinc	0.10%
Al	Balance

Table 2 Properties of AA6063 alloy [32]

Density	2.6 g/cm^3
Tensile strength	100 MPa
Rockwell hardness	60 HRB
Elongation	18–33%
Melting temperature	615 °C

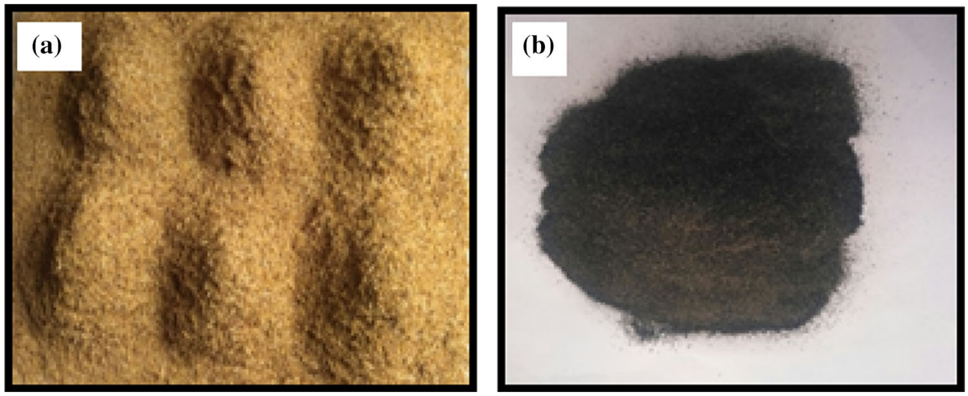


Fig. 1 **a** Photographs of waste rice husk, **b** photographs of carbonized RHA

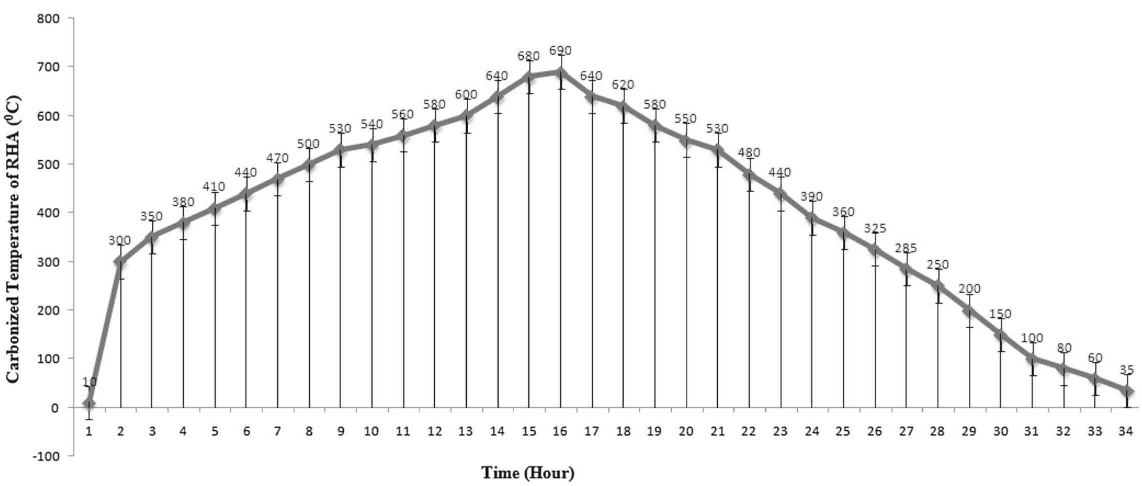


Fig. 2 Burning temperature and duration for RHA

2.2 Reinforcement Material

In the present investigation, rice husk ash (RHA) is selected as reinforcement material. First of all rice husk was washed and cleaned followed by drying in sun for 2 days with proper covering from plastic sheets to prevent it from dust and impurities. Dried rice husk ball was milled to be obtained in powder form. After ball milling, rice husk powder (RHP) was burned to obtain rice husk ash (RHA). The husk was burned at a temperature not exceeding 690 °C. The heating and cooling ramps, burning duration, in addition to the temperature inside the furnace are shown in Fig. 2. In the present study, rice husk powder is stated as uncarbonized RHA. Burnt rice husk ash is stated as carbonized RHA. Photographs of waste rice husk and carbonized RHA are shown in Fig. 1a, b. Rice husk ash chemical composition and its comparison with cement are shown in Table 3. As it is known, cement is a very hard material. There are lots of compositions such as SiO_2, CaO and Fe_2O_3 in the cement responsible for cement hard property as shown in Table 3. Comparative study of cement and RHA shows that SiO_2, CaO and Fe_2O_3 are present in both. From this study, it can be concluded that RHA may be used as good replacement of ceramic particles such as SiC, Al_2O_3 and B_4C.

Table 3 Comparative study of ceramic particles and RHA composition [33]

Compound	Cement (%)	RHA (%)
SiO_2	20	94.8
CaO	63.2	1.41
Fe_2O_3	3.3	1.61
K_2O	NA	1.33
TiO_2	NA	0.17
MnO	NA	0.28
CuO	NA	0.04

2.3 Development of Composites

In the present study, AA6063 matrix material and RHA reinforcement material synthesized with different weight proportions using stir casting rout. On the basis of the results based on pilot investigations, the compositions of reinforcements (uncarbonized RHA and carbonized RHA) were

Table 4 Composition selection

Sample no.	Compositions	Wt% of uncarbonized RHA	Wt% of carbonized RHA
1	AA6063 + 1.25% Uncarbo. RHA	1.25%	–
2	AA6063 + 2.5% Uncarbo. RHA	2.5%	–
3	AA6063 + 3.75% Uncarbo. RHA	3.75%	–
4	AA6063 + 5% Uncarbo. RHA	5%	–
5	AA6063 + 6.25% Uncarbo. RHA	6.25%	–
6	AA6063 + 7.5% Uncarbo. RHA	7.5%	–
7	AA6063 + 8.75% Uncarbo. RHA	8.75%	–
8	AA6063 + 10% Uncarbo. RHA	10%	–
9	AA6063 + 1.25% Carbo. RHA	–	1.25%
10	AA6063 + 2.5% Carbo. RHA	–	2.5%
11	AA6063 + 3.75% Carbo. RHA	–	3.75%
12	AA6063 + 5% Carbo. RHA	–	5%
13	AA6063 + 6.25% Carbo. RHA	-	6.25%
14	AA6063 + 7.5% Carbo. RHA	–	7.5%
15	AA6063 + 8.75% Carbo. RHA	–	8.75%
16	AA6063 + 10% Carbo. RHA	–	10%

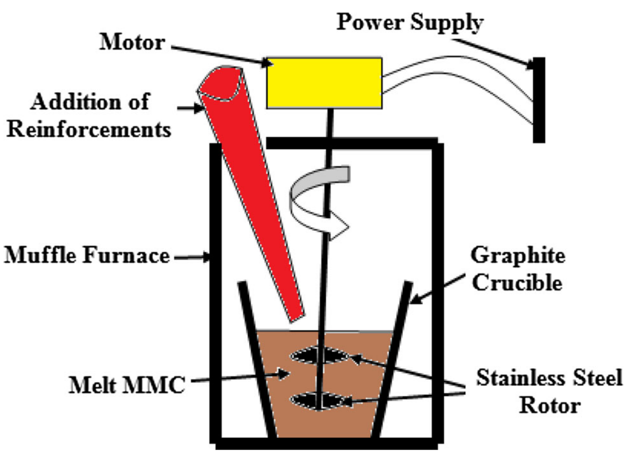


Fig. 3 Schematic diagram of stir casting rout [34]

selected and are shown in Table 4. The total percentage of all reinforcement particles varies from 1.25 to 10 wt% fraction in AA6063 matrix material. If the wt. percentage of reinforcement composition increases more than 10 wt%, then there is no more effects on physical and mechanical properties of metal matrix composite being observed. AA6063 aluminium alloy was heated about 700 °C in the graphite crucible as shown in Fig. 3. When temperature of melt AA6063 alloy was reached about 700 °C, then preheated uncarbonized and carbonized RHA particles added into melt matrix material.

2.4 Corrosion Testing

Corrosion problems in automobile sectors in manufacturing industries as well as air craft industries are one of the biggest issues in the current scenario. Keeping corrosion issue in the mind, corrosion test of all the prepared composite samples was also carried out to identify the RHA effect in the composition of developed composite. Corrosion test of all the samples was carried out in 3.5 wt% NaCl for 120 h.

2.5 Thermal Expansion

Material sustainability in the high-temperature environment is one of the most challenging issues nowadays. If material dimensions change in the high-temperature environment, then it cannot use further for any design parts. Keeping these facts in the mind, thermal expansion experiment was carried out to observe the material stability in high-temperature surrounding. Basically, thermal expansion is the tendency of matter to change in shape, area and volume in response to a change in temperature. To identify the thermal expansion, dimensions of all the prepared composites were kept 2500 mm^3 (25 × 10 × 10). All prepared composite samples were kept in muffle furnace at 450 °C constant temperature for 48 h.

3 Results and Discussion

3.1 Microstructure Analysis

Microstructure analysis was carried out to identify the presence of RHA in matrix material AA6063 as well as its distribution. When rice husk powder (RHP) burned, then it formed rice husk ash (RHA). When RHA is obtained after

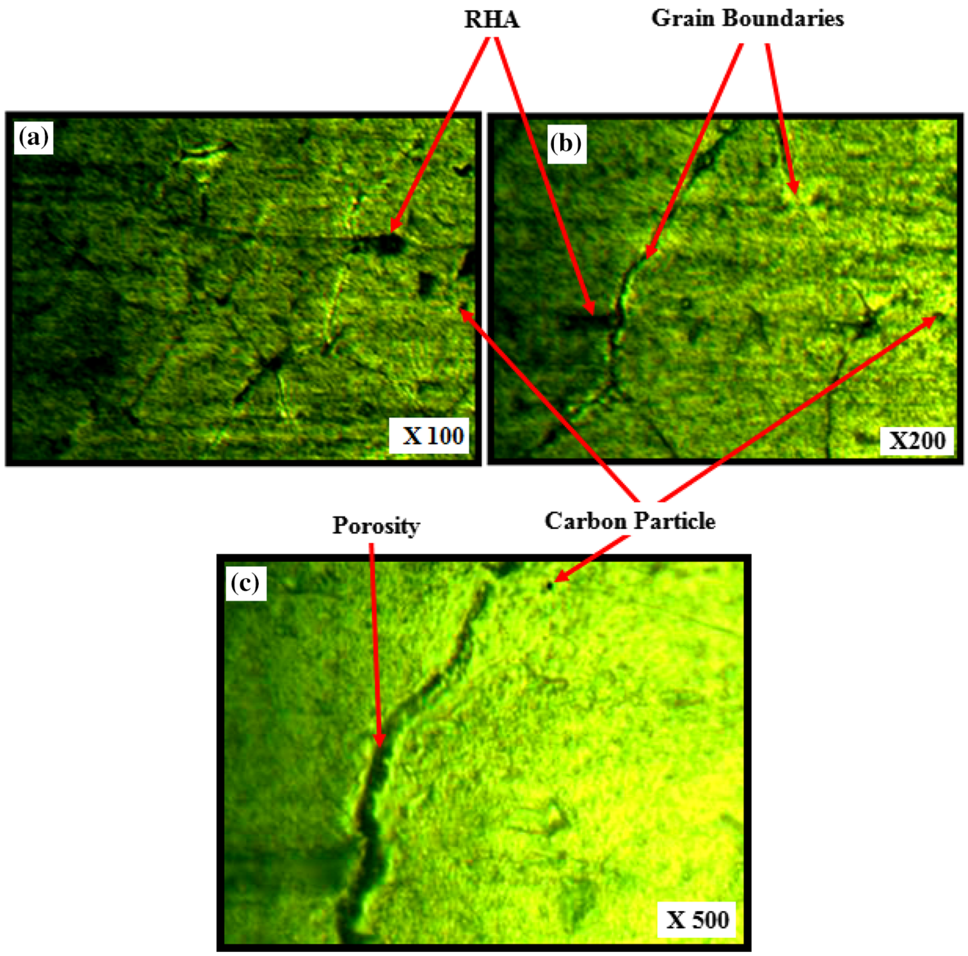


Fig. 4 Microstructure of AA6063/RHA green metal matrix composite

carbonizing process, then some carbon particles also form due to carbonizing process. Figure 4 shows the presence of carbon particles. These carbon particles are also responsible in the enhancement of hardness of metal matrix composite. Further, presence of RHA in aluminium also improved the mechanical properties as it contains SiO_2, CaO and Fe_2O_3 (Table 3). These hard particles are responsible for good mechanical properties of Al/RHA metal matrix composite. It was observed during the development of Al/RHA composites that when weight percentage of RHA increased beyond 7.5%, RHA particles move up in melt matrix material. These phenomena occur due to low density of RHA particles as compared to AA6063 alloy. Due to this phenomenon, various defects occur inside the matrix material such as porosity, blow holes and cracks. Figure 4c shows porosity of AA6063/10 wt% RHA metal matrix composite. Microstructure of AA6063/10 wt% RHA metal matrix composite shows that surface of casting is blistered. The structure consists of interdendritic aluminium–silicon, but dendritic cells are coarse. Carbon particles are visible as shown in Fig. 4c. However, optical micrograph of AA6063/7.5 wt% RHA metal matrix composite shows porosity-free composites (Fig. 5).

3.2 Tensile Strength

Tensile strength results of Al/RHA (carbonized RHA) composites and Al/RHP (uncarbonized RHA) composites show that tensile strength continuously increases by increasing the wt% of RHA and RHP in AA6063 matrix material as shown in Fig. 6. But, tensile strength began to decrease beyond 7.5 wt% of reinforcement (RHA and RHP). This decrement may occur due to the formation of porosity and blow holes as shown in Fig. 4c. Maximum tensile strength (148 MPa) was observed for composition AA6063/7.5 wt%. RHA composites. It was also observed that up to the 8.75 wt% of reinforcement addition in Al matrix, tensile strength of Al/Carbo. RHA composite is higher than tensile strength of Al/Uncarbo. RHA composite (indicated by green up bars) as shown in Fig. 6. However, tensile strength of AA6063/10 wt% carbonized RHA composite was found to be lower (indicated by red low bar) than tensile strength of AA6063/10 wt% uncarbonized RHA composite. When, carbonized RHA particles were added beyond 8.75%, most of the carbonized RHA particles were began to flow at upper surface of melt AA6063 aluminium alloy. Resulting, car-

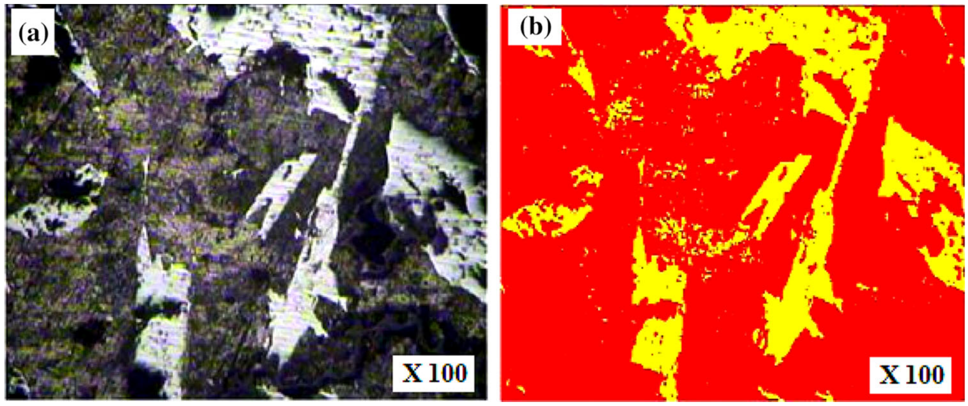
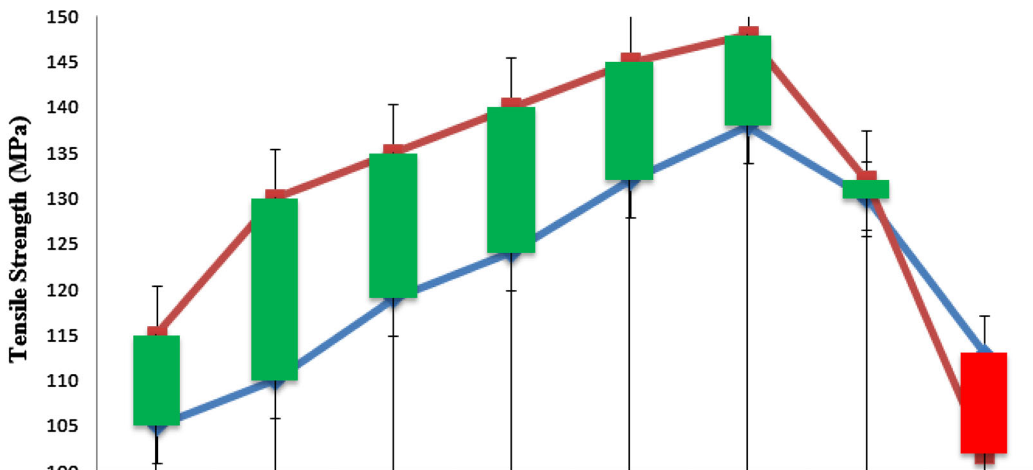


Fig. 5 Optical micrograph of AA6063/7.5 wt% RHA green metal matrix composite



RHA wt. %	1.25	2.5	3.75	5	6.25	7.5	8.75	10
Uncrbo RHA	105	110	119	124	132	138	130	113
Carbo RHA	115	130	135	140	145	148	132	102

Fig. 6 Tensile strength of Al/RHA composite

bonized RHA particles were not mixed properly. Hence, its strength was not much improved as compared to base metal.

3.3 Density and Porosity

Density and porosity analysis of green metal matrix composites were carried out. Theoretical density of uncarbonized RHA and carbonized RHA was 1.65 g/cm^3 and 1.60 g/cm^3, respectively. Density of AA6063 was 2.60 g/cm^3. Experimental density of composite was calculated from Archimedes principle, while theoretical density of composite was calculated from rule of mixture as given equation.

$$\rho_{AA6063/RHA} = Wt\%_{Al} \times \rho_{Al} + Wt\%_{RHA} \times \rho_{RHA}. \quad (1)$$

Porosity was calculated from given equation

$$P = \left(1 - \frac{\rho_{Experimental}}{\rho_{Theoretical}}\right) \quad (2)$$

Theoretical density and experimental density of Al/uncarbonized RHA composites and Al/carbonized RHA composites are shown in Figs. 7 and 8, respectively. Porosity is indicated by yellow lower deviation bars. It can be observed from the analysis that density of Al/uncarbonized RHA composites and Al/carbonized RHA composites continuously decreases by increasing the weight percentage of reinforcement. Minimum porosity was found to be 6.24% for Al/3.75 wt% uncarbonized RHA metal matrix composite. While for carbonized reinforced composite, minimum porosity was found for Al/1.25 wt%. However, maximum tensile strength was found to be 148 MPa for composition Al/7.5 wt% carbonized RHA composite. Here, porosity of same composition was observed 6.33%, which is acceptable with respect to other selected composition (shown in Table 4). Though, porosity of Al/6.25 wt% carbonized RHA composite was also found lower (4.72%) than Al/7.5 wt% carbonized RHA composite.

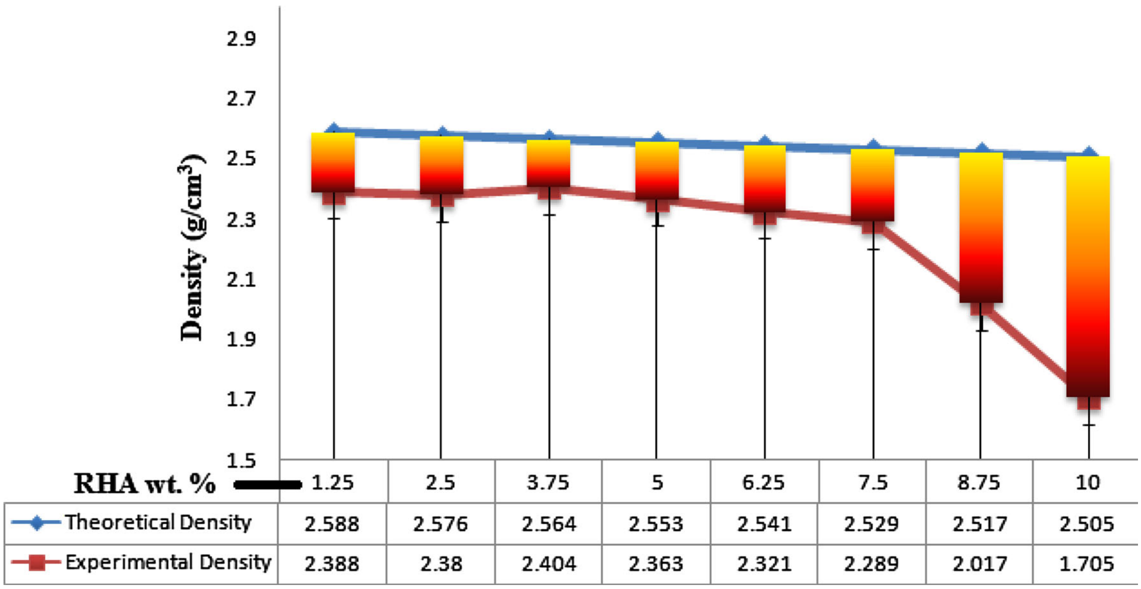


Fig. 7 Density and porosity analysis of uncarbonized RHA-reinforced green composites

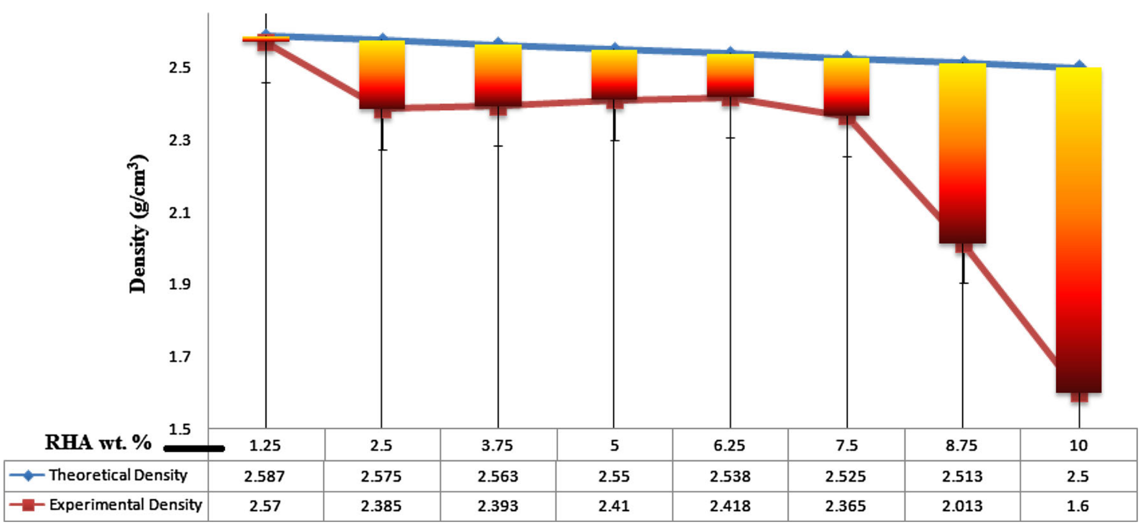


Fig. 8 Density and porosity analysis of carbonized RHA-reinforced green composites

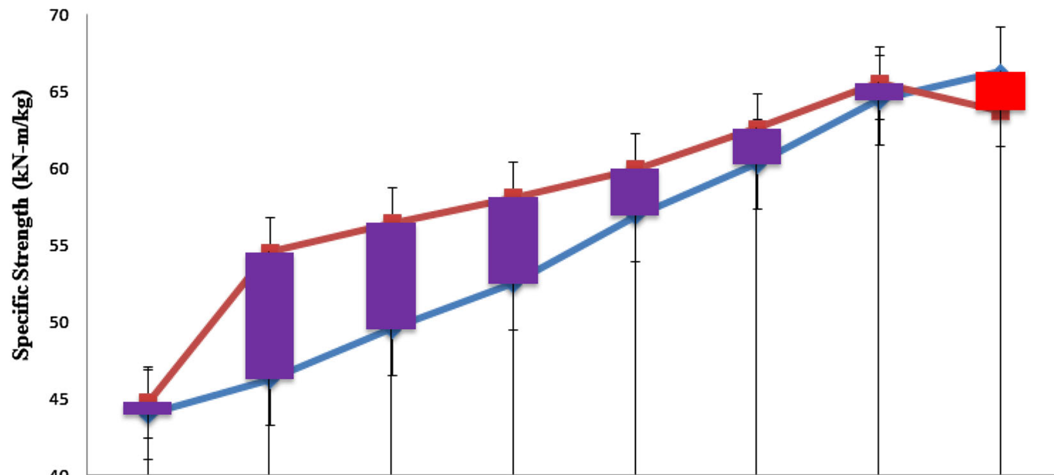
3.4 Specific Strength

Specific strength is also one of the most important factors in the selection of material. Usually, specific strength is obtained by dividing the tensile strength from its experimental density. In automobile industries, higher-density materials consume more fuel as compared to low-density materials. Due to this reason, high specific strength material (strong material with low density) is preferred in automobile industries. Keeping these facts in the mind, specific strength of composites was also calculated.

Specific strength of carbonized reinforced RHA composite shows higher specific strength as compared to uncarbonized reinforced RHA composites. Up deviation bar with purple colour indicates that specific strength is higher at each percentage of reinforcement up to 8.75 wt% for carbonized RHA-reinforced composites. For uncarbonized reinforced RHA composite, maximum specific strength (66.28 kN m/Kg) was found for 10 wt% of reinforcement as shown in Fig. 9. However, maximum specific strength for carbonized RHA-reinforced composite was found to be 65.57 kN m/Kg for 8.75 wt% of reinforcement. Specific strength was found to be 62.58 kN m/Kg for the 7.5 wt% of carbonized RHA composite.

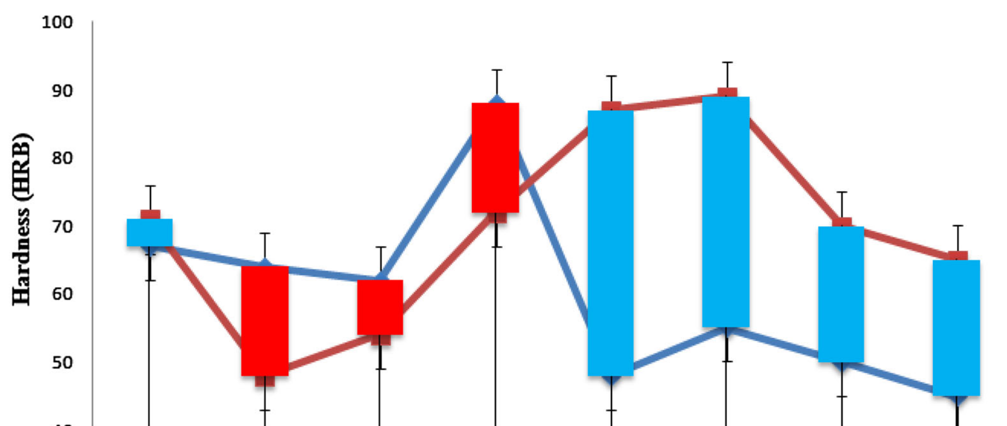
3.5 Hardness

Rockwell hardness of uncarbonized reinforced RHA composite and carbonized RHA-reinforced composite was measured on B scale for each percentage of reinforcement as



RHA wt. %	1.25	2.5	3.75	5	6.25	7.5	8.75	10
Uncarbo RHA	43.96984925	46.21848739	49.50083195	52.47566653	56.87203791	60.28833552	64.45215667	66.27565982
Carbo RHA	44.74708171	54.50733753	56.41454242	58.09128631	59.96691481	62.57928118	65.57377049	63.75

Fig. 9 Specific strength of composite materials



RHA wt. %	1.25	2.5	3.75	5	6.25	7.5	8.75	10
Uncarbonized RHA	67	64	62	88	48	55	50	45
Carbonized RHA	71	48	54	72	87	89	70	65

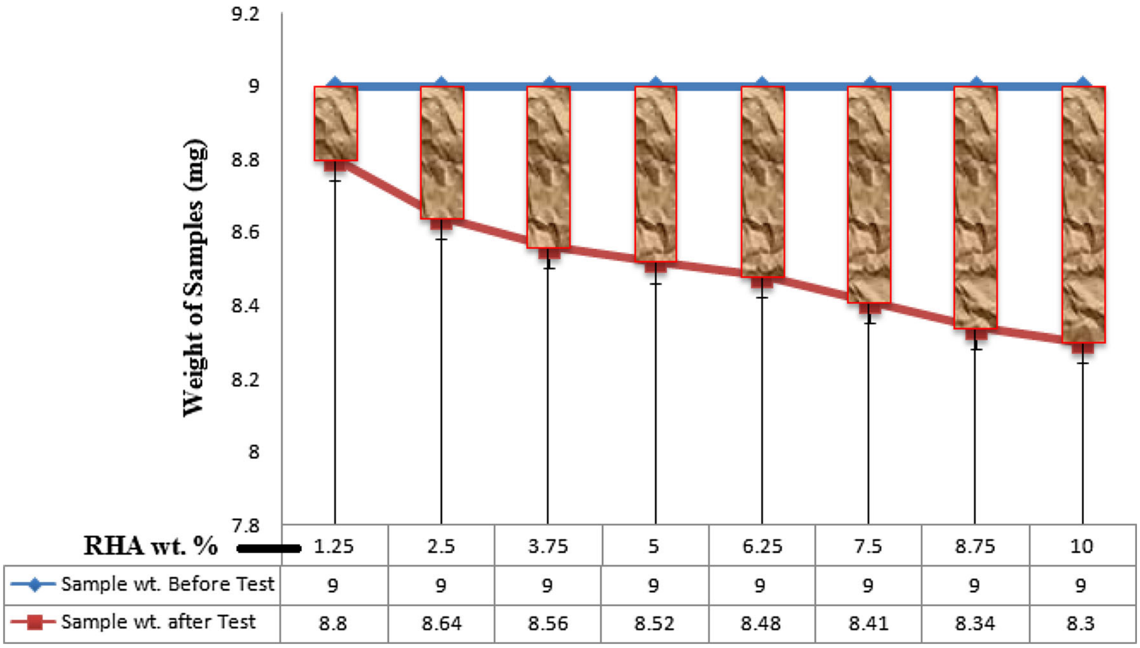
Fig. 10 Hardness of composite materials

shown in Fig. 10. Blue deviation bars show higher hardness of carbonized reinforced RHA composites as compared to uncarbonized RHA-reinforced composites. While, red deviation bars show higher hardness of uncarbonized reinforced RHA composites as compared to carbonized RHA-reinforced composites. Maximum hardness was found to be 89 HRB for Al/7.5 wt% carbonized RHA metal matrix composite.

3.6 Corrosion Test

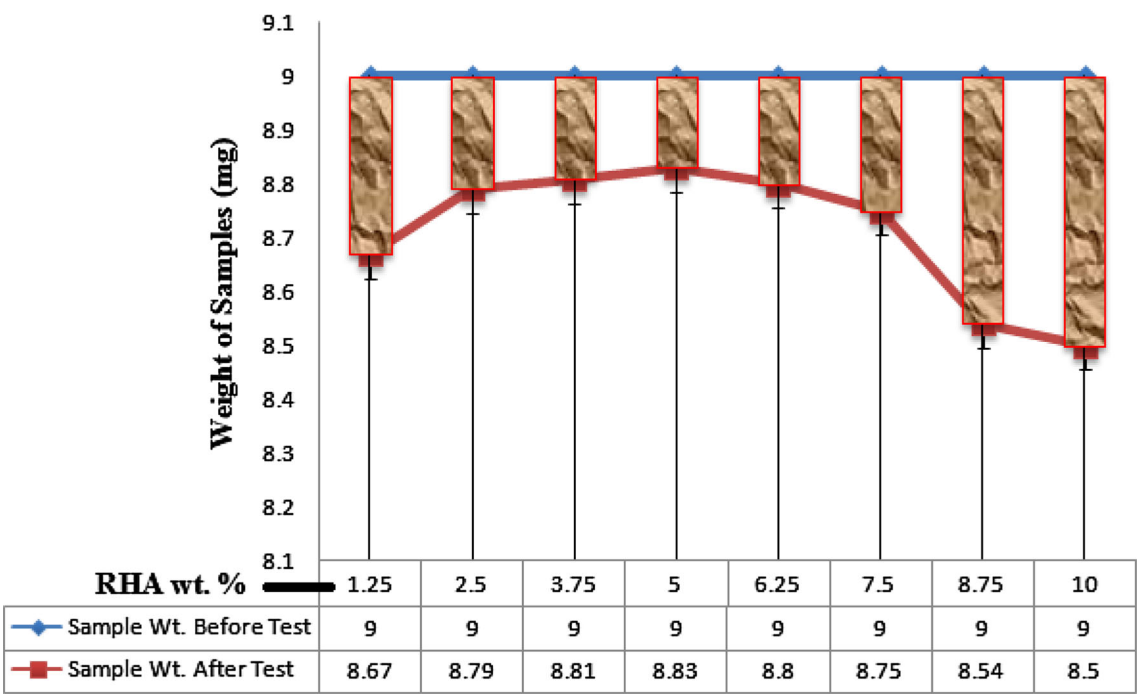
Corrosion test of all the samples was carried out to identify the durability (life) of composite with respect to surrounding moisture and environment. For the corrosion test, weight of all the samples was taken 9 gm to make uniformity. It can be observed from Fig. 11 that corrosion weight loss continuously increases by increasing weight percentage of uncarbonized RHA. Brown deviation bars indicate the corrosion loss of composites. Thus, this results show that uncarbonized RHA is not appropriate reinforcement to develop composite for durability point of view.

Figure 12 shows the corrosion loss of carbonized RHA-reinforced aluminium base composite. It can be observed from the analysis that corrosion weight loss decreases by increasing the weight fraction of carbonized RHA in alu-



RHA wt. %	1.25	2.5	3.75	5	6.25	7.5	8.75	10
Sample wt. Before Test	9	9	9	9	9	9	9	9
Sample wt. after Test	8.8	8.64	8.56	8.52	8.48	8.41	8.34	8.3

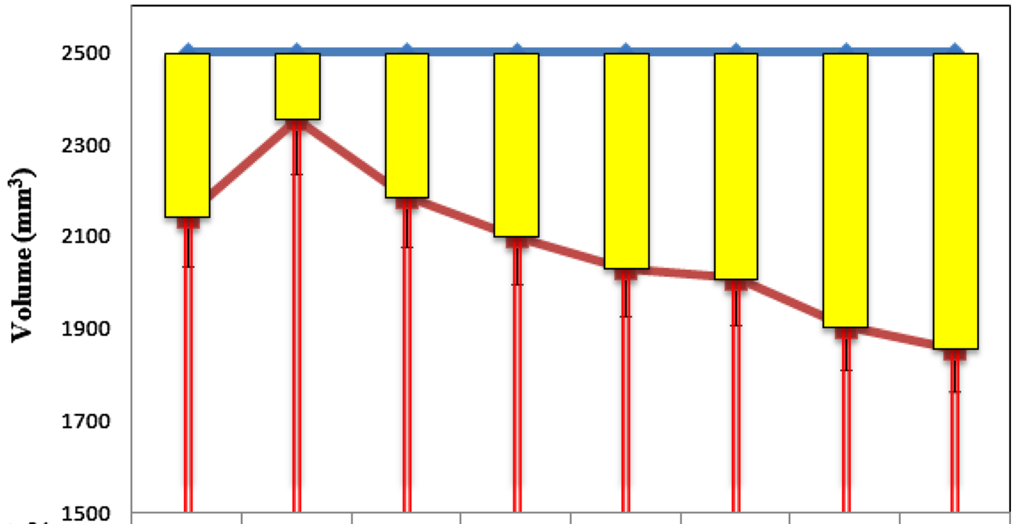
Fig. 11 Corrosion test results of uncarbonized reinforced RHA composites



RHA wt. %	1.25	2.5	3.75	5	6.25	7.5	8.75	10
Sample Wt. Before Test	9	9	9	9	9	9	9	9
Sample Wt. After Test	8.67	8.79	8.81	8.83	8.8	8.75	8.54	8.5

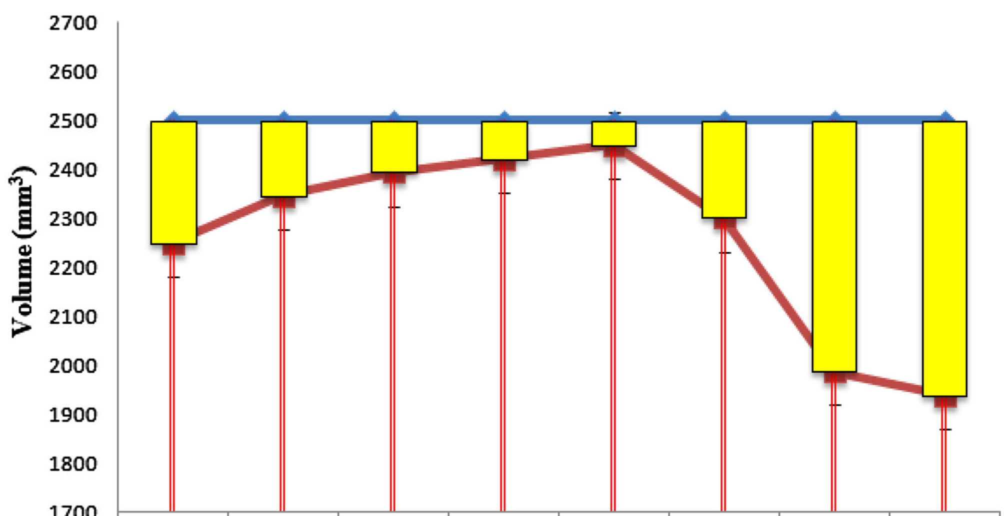
Fig. 12 Corrosion test results of carbonized reinforced RHA composites

minium up to 5%. It was also observed that beyond the weight fraction of 5%, corrosion weight loss of composite began to decrease. Maximum tensile strength and hardness were found for 7.5 wt% of carbonized reinforced RHA composite. Corrosion loss was found to be 0.25 mg for the same composition, which is acceptable with respect to other selected composition (shown in Table 4).



RHA wt. %	1.25	2.5	3.75	5	6.25	7.5	8.75	10
Volume Before Test	2500	2500	2500	2500	2500	2500	2500	2500
Volume after Test	2143.7	2355	2186.625	2100	2029.5	2008.8	1904	1856

Fig. 13 Thermal expansion test results of uncarbonized reinforced RHA composites



RHA wt. %	1.25	2.5	3.75	5	6.25	7.5	8.75	10
Volume before Test	2500	2500	2500	2500	2500	2500	2500	2500
Volume after Test	2249.1	2346.5	2394	2420.6	2449.02	2301.375	1986.875	1938

Fig. 14 Thermal expansion test results of carbonized reinforced RHA composites

3.7 Thermal Expansion

Thermal expansion property was identified to observe the suitability of material in high-temperature environment. Dimension (Volume: 2500 mm^3 (25 × 10 × 10)) of each sample was kept constant. Figure 13 shows the thermal expansion results of uncarbonized reinforced RHA metal matrix composite. It can be observed from the graph that shrinkage rate of samples continuously increases by increasing the weight percentage of uncarbonized RHA composite. Yellow deviation bars show the difference between original dimension of samples and final dimension of the samples. Minimum dimension difference was found to be 145 mm^3 for 2.5 wt% uncarbonized reinforced RHA com-

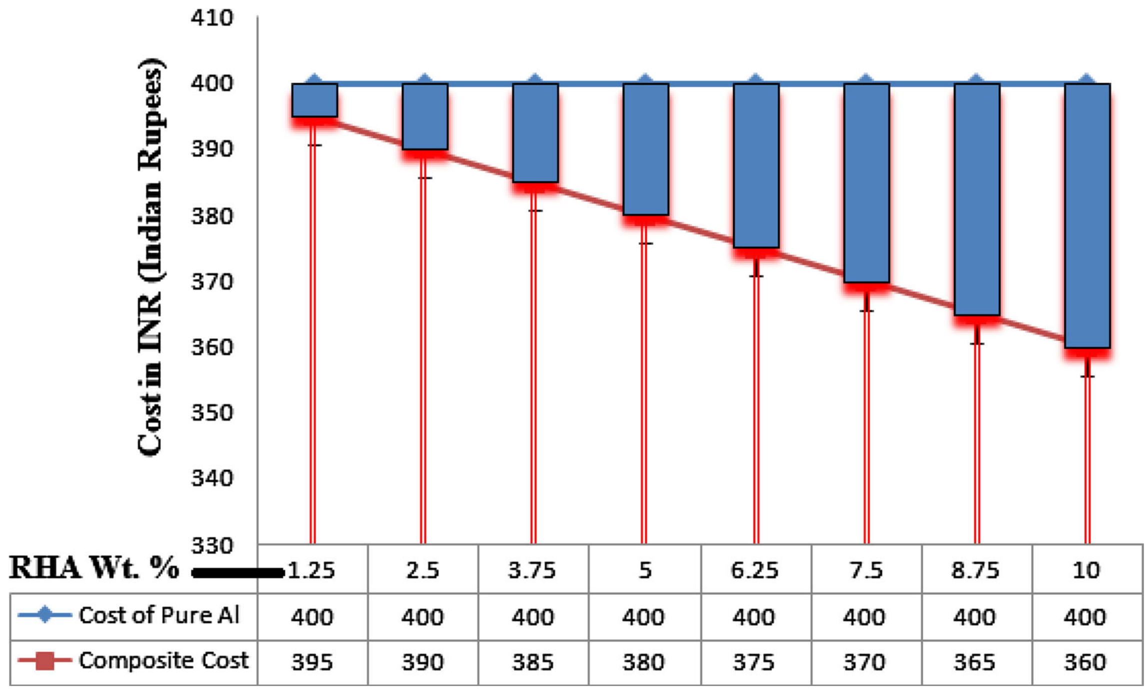


Fig. 15 Cost estimation of composites

posite as shown in Fig. 13. From this result, it can be concluded that uncarbonized RHA is not appropriate reinforcement to develop composite for thermal expansion application.

Figure 14 shows the thermal expansion result of carbonized reinforced RHA composite. It can be observed that shrinkage rate of composite decreases up to 6.25% by increasing the weight percentage of carbonized RHA. Beyond 6.25% of reinforcement, shrinkage rate of composite began to increase. Difference between original dimension of samples and final dimension of the samples is shown with the help of yellow deviation bars. Minimum deviation was found to be 50.98 mm^3 for 6.25% reinforcement. Thus, from this result it can be concluded that composition AA6063/6.25 wt% Carbo. RHA composite can be used in higher-temperature surrounding.

3.8 Composite Cost Estimation

In the selection of the materials, one of the most important factors is material cost and its availability. Keeping these facts in the mind, composite cost estimation was also carried out in this study. Base material was selected as AA6063 aluminium base alloy. It was purchased from the market directly for 400 Rs. /kg (Indian Rupees), as it was earlier discussed that RHA is a waste product and it is easily available free of cost. Usually, other ceramic particles such as SiC, B_4C and Al_2O_3 used as reinforcement in development of composite are purchased from chemical shops with average cost of 500 INR (Indian Rupees) to 14,000 INR (Indian Rupees). While, RHA is a waste product of rice mill and collected from the disposal land of industry. So, cost of RHA in this study is considered zero. So in this study, cost of RHA was considered as zero. It can be seen from Fig. 15 that by increasing the weight percentage of rice husk, cost of the composite continuously decreases. Results indicated that rice husk ash may be used as good partial replacement of ceramic particles.

3.9 Comparing Results of Present Investigation with the Previous Work

Table 5 shows the comparative study of the present investigation results with previous published RHA-reinforced composite material results. Density, tensile strength, rockwell hardness, specific strength, porosity, corrosion loss and thermal expansion are investigated in the present investigation. Results showed that after carbonizing the rice husk powder (RHP) by proper heating and cooling ramp process, obtained rice husk ash (RHA) enhanced much mechanical properties of composite after mixing it in matrix material as shown in Table 5. However, Narasaraju et al. [35], Verma et al. [18], Dinaharan et al. [14] and Gladston et al. [20] also used RHA as reinforcement material with aluminium and showed that mechanical properties of composite using RHA are improved as shown in Table 5.

Table 5 Comparing properties of the present investigation with the previous work

Reference no.	Authors	Property of base material		Composite properties			Percentage improved
Present study	Dwivedi et al.	AA6063 (0 tempered)		Composition	Parameters	Value	
		Density	2.6 g/cm^3	AA6063 + 7.5% Carbo. RHA	Theoretical density	2.52	3.17% (reduced)
		Tensile strength	100 MPa	AA6063 + 7.5% Carbo. RHA	Tensile strength (maximum)	148 MPa	48%
		Rockwell hardness	60 HRB	AA6063 + 7.5% Carbo. RHA	Rockwell hardness (maximum)	89 HRB	48.33%
		Specific strength	38.46 kN m/kg	AA6063 + 7.5% Carbo. RHA	Specific strength (maximum)	62.57 kNm/kg	62.68%
				AA6063 + 7.5% Carbo. RHA	Porosity (minimum)	6.33%	–
				AA6063 + 5% Carbo. RHA	Corrosion loss (minimum)	0.17 mg	–
				AA6063 + 6.25% Carbo. RHA	Thermal expansion (minimum)	50.98 mm^3	–
35	Narasaraju et al.	Property of base material		Composite properties			Percentage improved
		AlSi10Mg		Composition	Parameters	Value	
		Ductility	2%	AlSi10Mg + 10% Fly Ash + 10% RHA	Ductility	3.2%	60%
		Tensile strength	350 MPa	AlSi10Mg + 10% Fly Ash + 10% RHA	Tensile strength	410 MPa	17.14%
		hardness	62.58 BHN	AlSi10Mg + 10% Fly Ash + 10% RHA	Hardness	69.02 BHN	10.29%
18	Verma et al.	Property of base material		Composite Properties			Percentage improved
		AA7075		Composition	Parameters	Value	
		Compressive strength	340.109 MPa	Al7075 + 5% B4C + 5% RHA	Compressive strength	536.55 MPa	57.75%
		Tensile strength	200.10 MPa	Al7075 + 5% B4C + 3% RHA	Tensile strength	235.78 MPa	17.88%
		Hardness	70.08 HV	Al7075 + 5% B4C + 5% RHA	Hardness	121.42 HV	73.25%
14	Dinaharan et al.	Property of base material		Composite Properties			Percentage improved
		AA6061		Composition	Parameters	Value	
		Tensile strength	220 MPa	AA6061/18 vol.% RHA	Tensile strength	285 MPa	38.63%
20	Gladston et al.	Property of base material		Composite Properties			Percentage improved
		AA6061		Composition	Parameters	Value	
		Tensile strength	150 MPa (with deviation bar)	AA6061/8% RHA	Tensile strength	235 MPa (with deviation bar)	57.42%
		Hardness	55 HV (with deviation bar)	AA6061/8% RHA	Hardness	150 HV (with deviation bar)	167.27%

4 Conclusions

In this study, rice husk ash was used as a partial replacement of ceramic particles. Following conclusions may be drawn from the exhaust analysis.

1. Rice husk ash is a waste agricultural product which may be used as a partial replacement of ceramic particles as it contains some hard phases such as SiO_2, CaO and Fe_2O_3.
2. Production of ceramic particles such as SiC, B_4C, Al_2O_3 are very costly as well as during production of these ceramic particles lots of green house gases emit. Some problem of environment can be resolved by using RHA as partial replacement of ceramic particles.
3. Aluminium-based metal matrix composite was successfully developed with the help of RHA as reinforcement using stir casting rout.
4. Microstructure results showed proper evidence of RHA particles in the metal matrix composite sample.
5. Maximum tensile strength and rockwell hardness were found to be 148 MPa and 89 HRB for 7.5 wt% reinforcement of carbonized RHA particles. Results showed that tensile strength and hardness increased about 48% and 48.33%, respectively, with respect to base metal (AA6063).
6. Minimum percentage porosity was found to be 4.72% for Al/6.25 wt% carbonized RHA metal matrix composite. However, maximum tensile strength and hardness were found for Al/7.5 wt% carbonized RHA metal matrix composite. Porosity of Al/7.5 wt% carbonized RHA metal matrix composite was found to be 6.33%, which is acceptable.
7. Maximum specific strength and minimum corrosion loss were found to be 65.57 kN m/Kg for 8.75 wt% of carbonized reinforced RHA and 0.17 mg for 5 wt% of carbonized reinforced RHA, respectively.
8. Density and cost of RHA-reinforced composite continuously decreases by increasing the percentage of reinforcement.
9. Minimum thermal expansion was observed for 6.25 wt% of carbonized reinforced RHA composite.
10. From the analysis, it was observed that carbonized RHA-reinforced composite provides better result as compared to uncarbonized RHA-reinforced composite.

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