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Processing and wear behavior optimization of B_4C and rice husk ash dual particles reinforced ADC12 alloy composites using Taguchi method

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Abstract. The composite material comprises either two or more constituents having dissimilar physical and chemical properties. The composite is prepared by various techniques, but the stir casting method has been widely used, as it is simple and cost-effective. In the present work, the composites from ADC12 Aluminum Alloy-Boron Carbide (B_4C) (wt.5%) and varied wt % of Rice Husk Ash (RHA) were developed with the help of the stir cast technique. Composite having 3, 6, 9 wt.% of RHA were considered for the wear analysis. The wear analysis of hybrid composites was studied with the help of Taguchi method and also optimum values were determined. The tribological study was conducted on the Pin on disk testing apparatus under dry sliding conditions. The L27 orthogonal array has been preferred in the present work to include three factors and three levels. The selected factors are Speed (N), Load (W), RHA, and wear depth as system output (yield). Analysis of variance has been carried out to know the parameters' influence and level of contribution to the wear loss. For, the validation of the analysis results the experimental test was carried out for the optimum values. To understand the wear mechanism in composites the samples were analyzed using Scanning Electron Microscopic (SEM) and it has been observed that both abrasive, as well as adhesive wear, did occur on the contact surface of the specimens.
Keywords: ADC12 Alloy, B_4C, rice husk ash, microstructure, wear, optimization, Taguchi

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1. Introduction

More recently, extensive research work has been conducted on agro based waste products because these agro-waste products are easily available, less dense, have reduced cost and are environmentally friendly. Several research studies show that Agro based waste byproducts like maize stalk ash, bamboo leaf ash, corn cob ash, RHA, bagasse ash, and bean shell waste ash have been used as reinforcing materials to increase the Wear and Mechanical characteristics of aluminium-based composites. The latest sophisticated materials are an aluminium alloy matrix supplemented with SiC and B_4C particulate [1,2]. Hard materials are commonly used as reinforcements due to their ability to improve qualities such as tensile and compression strengths, as well as their advantages in tribological applications. Reinforcements with appropriate particles are commonly used to improve mechanical qualities. B_4C and RHA fibres have also been used as reinforcing materials in MMC because of their high strength and low density. Aluminium MMCs made by solidification processes with these particulates as reinforcing material represent a class of low-cost, suitable materials for a variety of engineering applications in the automobile industry, such as brake pads, bushes, and bearings [3,4]. The aluminium metal matrix material reinforced with B_4C has the potential to develop a material with improved thermal conductivity, incredible mechanical capabilities, and good damping behaviour at high temperatures [5]. However, there is a wettability problem between aluminium and the B_4C-RHA reinforcements, and oxidation of the particles at high temperatures causes industrial problems and material cavitation.

At increased temperatures, current research on AMMC with ceramic reinforcement particles has revealed an increase in wear resistance and improvements in mechanical properties [6,7]. Due to the presence of B_4C, matrix deformation, load distribution, and micro defects that frequently occur along the friction track could be effectively prevented.

From the literature, it is clear that numerous investigators conceded the investigations on hybrid composites using aluminium alloys of different series such as 1xxx -7xxx as matrix material but from literature, it is very rarely seen that usage of aluminium alloy ADC12 as matrix material. Further combination of reinforcements like boron carbide and agro waste product RHA containing oxide in the development and characterization of hybrid MMCs was not done.

In the present work, samples of ADC12 Aluminum Alloy-B_4C-RHA composites were prepared using stir casting. For the preparation of composites ADC12 aluminum alloy is used as matrix material, B_4C particles, and RHA particles were used as reinforcing materials. The tribological properties of ADC12 aluminum alloy-B_4C-RHA AMCs were studied by Taguchi's technique. It has been understood that the rate of wear in composites was influenced by the amount of RHA (reinforcing material) used and wear parameters like the sliding speed and applied load. Pin on Disk wears testing apparatus was used to find out the wear of the composite samples which were initially developed by stir casting method [8,9]. The design of experiments was planned and conducted as per the L27orthogonal array by Taguchi technique. The agro-waste derivatives were found very much influential as reinforcing materials [10] on properties of composites materials and also promising resources for the aluminium based metal composites on a large scale. In recent times, several investigations were aimed at the optimization of the production parameters and wear parameters.

2. Taguchi method

Taguchi method [11-13] is a powerful technique for designing of experiments to obtain a high yield from the process or system using orthogonal arrays (OA). Taguchi techniques are strategically ordered experiments to minimize deviations in the desired quality. It is a logical and easy statistical approach to finding popular designs for better execution, high quality, and less expensive. The Signal-to-Noise Ratio (S/N Ratio) is determined from the output response in Taguchi technique (experimental results-wear loss). The signal-to-noise ratios were calculated with the following goals in mind: smaller is better, nominal is best, and larger is best. The research in this work was carried out with the goal of making the wear depth as small as possible, and the equations employed are listed below [14].

$$S/N = -10 \times log\left(\sum \frac{Y^2}{n}\right).$$

Here Y – result output at a certain level of combination and n – Number of result output at a certain level of combination.

The Taguchi method uses the problem's objective to obtain the Signal to Noise (S/N) ratio values. With the help of obtained S/N ratio values, the ideal combinations of variables have been presented. Analysis of variance technique has been utilized to know the statistically required factor and its contribution. To crosscheck the obtained ideal parameters a validation test was also conducted.

3. Experimentation

Materials used and composites preparation. A wide range of metals are utilized in MMCs and the decision of the substance relies on the sort of utilization. Henceforth alloy frameworks, for example, aluminium, copper, iron, magnesium, titanium, and nickel have been used as the base. It is observed that Fe-based car parts in the long run all be supplanted with more lightweight metals, e.g., aluminium combinations. ADC12 Alloy is Al-Si-Cu-based cast amalgams that have high mechanical properties and great castability so these composites have been utilized for automotive parts, for example, chamber blocks, transmission cases, carburettors, brake cushions, and so forth. For the current work grid material picked is ADC12 Alloy. Table 1 is showing the chemistry of ADC12 alloy. Some important physical, mechanical and thermal properties of ADC12 alloy are shown in Table 2.

Table 1. Chemistry of ADC12 alloy

Elements (wt. %)	ADC12 (Standard wt. %)	ADC12 (Actual wt. %)
Si	9.60-12.00	10.60
Fe	1.30 Max.	0.84
Cu	1.50-3.50	2.13
Mn	0.50	0.09
Mg	0.30 Max.	0.07
Zn	1.00 Max.	0.89
Ni	0.50 Max.	0.07
Pb	0.30 Max.	0.02
Ti	0.20 Max	0.05
Aluminium	Balance	Balance

Table 2. Properties of ADC12 alloy

Density (g/cc)	2.7
Melting point (°C)	660
Poisson's Ratio	0.33
Modulus of Elasticity (GPa)	70-80
Hardness (HV)	70
Tensile Strength (MPa)	165-331
Co-efficient of Thermal Expansion(mm / K^{-1})	31.1×10^{-6}

Boron synthetically combined with carbon results in a very hard ceramic known as boron-carbide, B_4C being the 3rd hardest material after cubic boron nitride (CBN) and diamond is used as abrasion material and to combat wear. Because of its high hardness and low density, the material can be used in aluminium matrix alloy in the form of particulates to produce composition material. In the present work, B_4C particulates with 40 micron size are used which were brought from Speed-Fam Ltd., Chennai. The SEM analysis of B_4C particulates has been carried out at BMSCE, Bangalore, Karnataka, India. Figure 1 shows the micro B_4C particles. The composition of B_4C particles is shown in Table 3. Further, Table 4 indicates the different physical and mechanical properties of B_4C.

Table 3. Composition of B_4C particles

Elements	Composition wt. %
Boron (B)	63.68
Carbon (C)	36.32

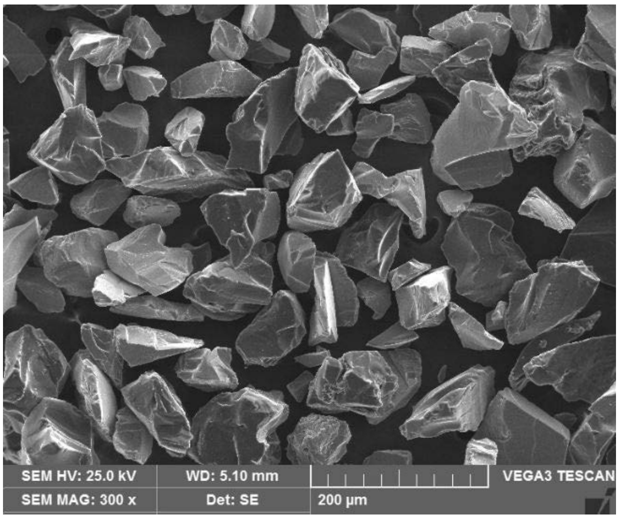

Fig. 1. Scanning Electron Microphotograph of B_4C particles

Table 4. Physical and mechanical properties of B_4C

Crystallography	Rhombo-hedral
Color	Black
Specific Gravity	2.52
Knoop 100 hardness	2900 - 3580
Shape	Blacky-Angular
Melting Point °C	2350
Density (g/cc)	2.52
Young’s Modulus (GPa)	450-470
Thermal Conductivity (at 25°C W/m – K)	30-42

RHA is one of the farming waste substances and is characteristic fortification material. An enormous measure of rice husk is produced over the world consistently. This amount of waste is a challenge to dispose of. The momentum research focused to change over the RHA squander into valuable support material by getting Si through rice husk flakes. The concoction synthesis of arranged RHA is shown in Table 5. The normal molecule size of utilized RHA is 30 µm. Figure 2 is the SEM image of RHA particles and properties are available in Table 6.

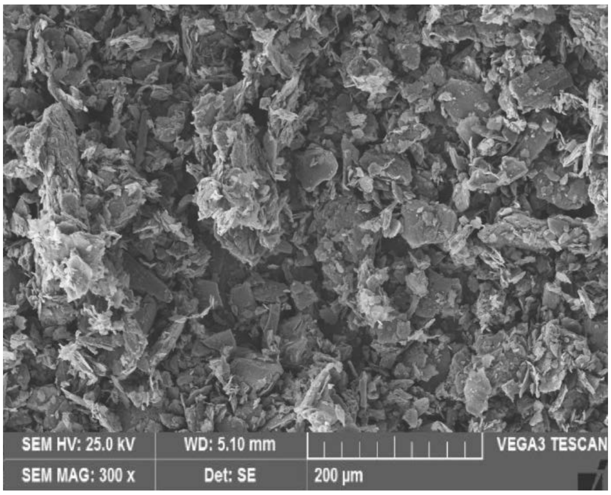

Fig. 2. Scanning Electron Microphotograph of RHA particles

Table 5. Chemistry of RHA

Elements	SiO_2	K_2O	CaO	MgO	Fe_2O_3	Al_2O_3	C	Na_2O	LOI*
Wt. (%)	93.1	1.28	1.1	0.56	0.49	0.47	0.33	0.6	2.61

*LOI-Loss of Ignition

Table 6. Physical and mechanical properties of RHA

Crystallography	Rhombo-hedral
Color	Black
Specific Gravity	2.52
Knoop 100 hardness	2900 - 3580
Shape	Blacky-Angular
Melting Point °C	2350
Density (g/cc)	2.52
Young’s Modulus (GPa)	450-470
Thermal Conductivity (at 25°C W/m – K)	30-42

The cost-effective and uncomplicated stir casting was selected for the fabrication of the composites in the current research. ADC12 aluminum Alloy-B_4C-Rice Husk Ash hybrid composites with a varying weight percentage of Rice husk ash were fabricated with the help of the stir casting technique. During the development of Aluminum alloy based composite, ADC12 Aluminum Alloy was reinforced within B_4C-Rice husk ash material. The different hybrid composites were prepared having B_4C fixed wt5% and Rice husk ash particulates varied with wt.% 3,6,9. Initially, the compact chunks of ADC12 Aluminum Alloy were placed in a crucible, and the temperature was raised up to 750°C in a furnace. Parallelly, B_4C particles of 40μm and Rice husk ash powder particles of 30μm were heated in an oven whose temperature was set to 300°C this preheating was carried out in order to remove trapped moisture or any unwanted organic elements. Now, the calculated amount of preheated B_4C particles and RHA powder were introduced within the molten metal of aluminum alloy, and brisk stirring of molten metal is carried out using an electric motor stirrer until there is a formation of a vortex. The stirring speed was maintained in the range of 500±25 rpm with the help of a tachometer. Continuous stirring for 5-7 minutes was conducted so that each and every B_4C and RHA particles were mixed in the molten metal thoroughly and 1% wt of magnesium chips were added to the molten mixture to improve the wettability of the composite mixture. Now, the thoroughly mixed molten composite mixture is poured into a graphite-coated metal mould die at room temperature. Once the molten metal mix solidifies it is ejected carefully from the dies and machined to ASTM standards for the conduction of wear tests.

Design of experiment (DOE). Many orthogonal arrays available for the design of experiments are based on several parameters at their respective levels. For the optimization of parameter levels along with the reduction in cost and time of experimentation, the selection of a perfect orthogonal array is very important. Orthogonal design helps us in knowing the effect of multiple factors on wear depth. For determining the wear behavior in the present work, the three design factors chosen are Speed (N), Load (W), and RHA at three levels as in Table 7.

Table 7. Design factors and their levels

Levels	Design Factors		
	Speed N, (rpm)	Load W, (N)	RHA (wt.%)
1	250	10	3
2	500	20	6
3	750	30	9

The values of design factors obtained at three different levels are shown in Table 4 above. The software "Minitab" helps in improving factor interaction along with accuracy by selecting design factors, levels, and L27 orthogonal array during analysis. L27 is the number of trial runs i.e., 27 runs are carried out during experimentation. Each column is assigned to the respective factor and interconnected factors.

Table 8 below represents L27 orthogonal array. Each of the columns is assigned with a respective parameter. Speed (N) is assigned to the first column similarly, the second and fifth columns are assigned to Load (W) and RHA respectively. The rest of the columns assign themselves to the errors and interrelated factors. The trial runs were conducted based on L27 orthogonal array and the degree of design factors represented in each row is shown in Table 8.

To diminish the wear depth S/N ratios were calculated by considering the objective as smaller is the better. The analysis of variance ANOVA for experiment results was applied to find the contribution of each factor in the output.

Wear test. Pin on Disk machine (Ducom-20) was used to analyze the wear characteristics and behavior of Al/B4C/RHA hybrid composite under dry conditions. ASTM G99 wear test standards were considered for the conduction of experiments over a circular specimen with diameter of 10 mm and length of 15 mm. Under dry sliding conditions, By considering the parameters like varying load of 10N, 20N, 30N, and sliding distance of 1000 m also keeping track diameter of 50 mm wear rate was found out. The developed hybrid composite comprising of Al/B_4C/RHA standard test specimens was forced against a revolving steel disk whose hardness is 55 HRC and a part of wear testing machine i.e., steel disk revolved and the pin (specimen) is secured by a holder clamp. The required input data like speed, time, load setting, etc. were entered into the system software also the required manual application of load was carried out. Now as per the orthogonal array the wear tests was conducted for each set of the specimen by varying the speeds from 250 RPM to 750 RPM. After the wear test, wear loss was determined from the depth of the sample by the weighing machine as system response, and digital data were collected. Analysis was done by digital data collected from the experimentation used as an output response as in Table 9.

Table 8. Orthogonal array L27 (3^{13}) of Taguchi

Experiment No.	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	1	2	2	3	1
17	2	3	1	2	2	3	1	1	2	3	3	1	2
18	2	3	1	2	3	1	2	2	3	1	1	2	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	1	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	1

4. Results and discussion

Microstructural analysis. The microstructural characterizations of specimens are inspected by SEM equipment. Figure 3 shows the SEM micrographs of ADC12 material with B_4C and RHA micro particulates reinforced composites without heat treatment. Figure 3 (a) shows the SEM of pure ADC12 material. Figure 3 (b-e) shows the SEM images of ADC12 alloy with a constant 5 wt. % of B_4C and 3, 6, 9 and 12 wt. % of RHA hybrid composites respectively. The SEM micrograph of as-cast ADC12 is free from particulates as it is an unreinforced alloy. Since the ADC12 alloy contains Si as the key alloying element, the presence of silicon is clearly represented by the leafy structure in the matrix. In addition, Figure 3 (b-e) shows that the B_4C and RHA particles in the produced hybrid composites are homogeneous. The enhanced reinforcing content in the ADC12 alloy composites is also visible in the microphotographs. As can be observed in Fig. 3 (e), adding 5 wt. percent B_4C microparticles and 12 wt. percent RHA particulates to the ADC12 matrix in two stages improved the microstructure of the composite significantly. The prepared samples with 5 wt. % of B_4C and 3, 6, and 9 wt. % of RHA particulates composites are free from clustering as in Fig. 3 (b-d). As wt. % of RHA particulates increased to 12 wt. % in ADC12 with 5 wt. % of B_4C, agglomeration is observed in the hybrid composites due to higher wt. % of low-density particles. It is also noted in Fig. 3 (b-e) that the micro B_4C and RHA particles are distinct and show a good bonding between the ADC12 alloys.

Table 9. Wear test and S/N ratio results

Experiment No.	Speed (RPM	Load (N)	RHA (%)	Wear (mm^3/m)	S/N Ratio
1	250	10	3	0.0055981	45.0393
2	250	10	6	0.0041500	47.6390
3	**250**	**10**	**9**	**0.0022882**	**52.8103**
4	250	20	3	0.0130621	37.6797
5	250	20	6	0.0105636	39.5237
6	250	20	9	0.0072458	42.7982
7	250	30	3	0.0216458	33.2925
8	250	30	6	0.0192409	34.3155
9	250	30	9	0.0141103	37.0093
10	500	10	3	0.0108229	39.3131
11	500	10	6	0.0083000	41.6184
12	500	10	9	0.0053390	45.4508
13	500	20	3	0.0246315	32.1702
14	500	20	6	0.0211273	33.5031
15	500	20	9	0.0156357	36.1176
16	500	30	3	0.0373204	28.5611
17	500	30	6	0.0339546	29.3820
18	500	30	9	0.0263138	31.5963
19	750	10	3	0.0171674	35.3059
20	750	10	6	0.0139591	37.1028
21	750	10	9	0.0102967	39.7460
22	750	20	3	0.0369472	28.6484
23	750	20	6	0.0324455	29.7769
24	750	20	9	0.0240256	32.3865
25	750	30	3	0.0541146	25.3337
26	750	30	6	0.0498000	26.0554
27	750	30	9	0.0392800	28.1166

Analysis of S/N ratio. The S/N ratio for several numbers of the experiment is achieved from wear loss test conducted and in order to obtain as less as possible wear depth for ADC12 Al alloy/B_4C/RHA hybrid MMC using Taguchi technique. Small is always a good objective which in turn is used to obtain the S/N ratio. The values obtained for the wear test and the respective S/N ratio results are shown in Table 9 above.

Table 10 depicts the response table of means of wear loss and Table 11 S/N ratios being smaller is better for speed (N), Load (W), and wt.% of RHA (RHA). The difference between maximum response value and minimum response value for a certain factor at different levels is called a delta value. Also, based on these delta values ranking are assigned to each factor in the wear loss response table. The Load (L) factor has the highest delta value so it is assigned as rank 1. Similarly, the Sliding speed (S) factor and wt. % of RHA factors are allocated as second and third rank based on delta values.

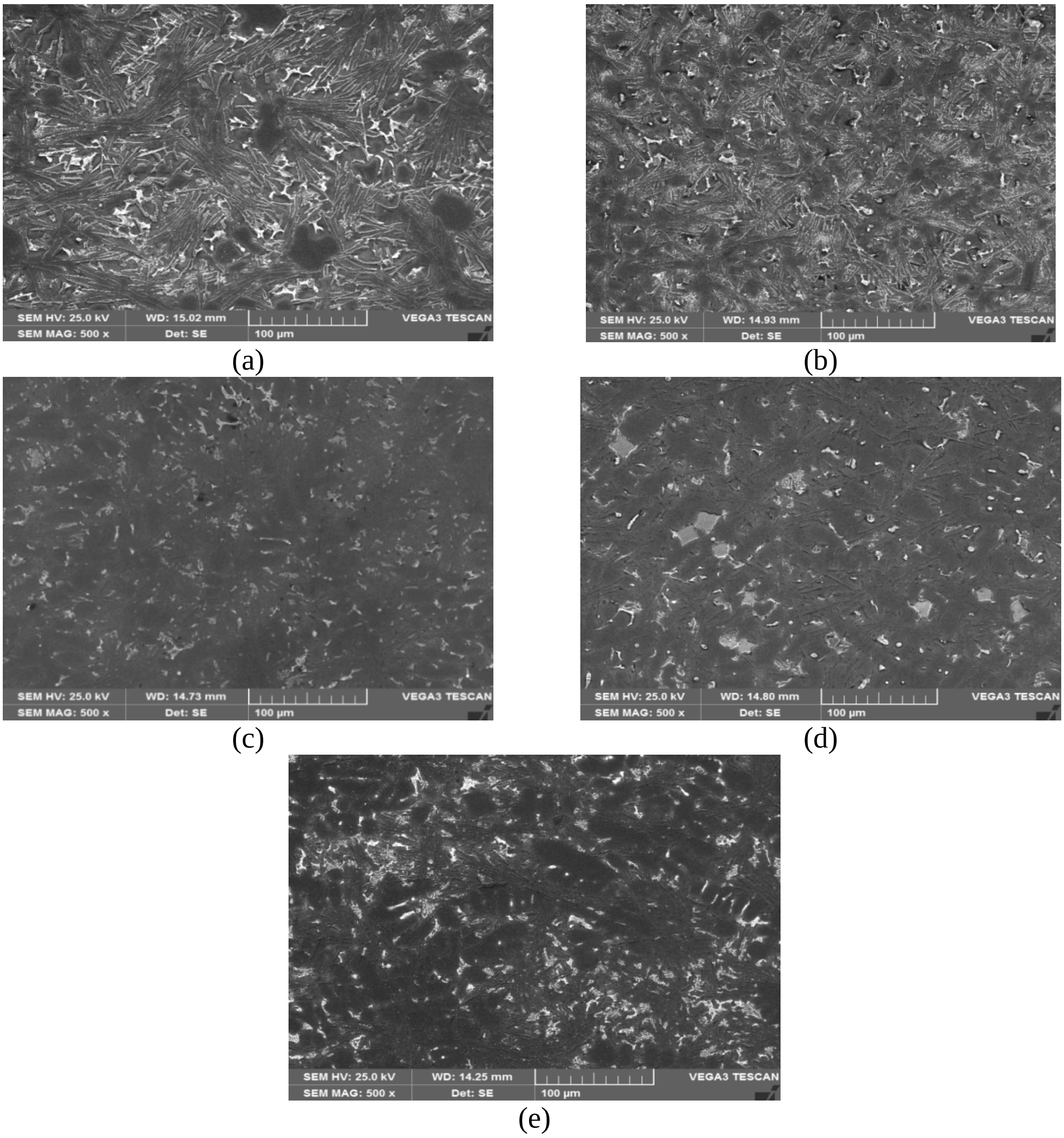

Fig. 3. (a-e) Scanning electron microphotographs of (a) ADC12 alloy (b) ADC12 Alloy-5% B_4C-3% RHA (c) ADC12 Alloy-5%-B_4C-6% RHA (d) ADC12 Alloy-5% B_4C-9% RHA (e) ADC12 Alloy-5% B_4C-12% RHA composites

Table 10. Response table for means of wear loss

Means of wear loss			
Level	Speed	Load	RHA
1	0.010878	0.008658	0.024590
2	0.020383	0.020632	0.021505
3	0.030893	0.032864	0.016059
Delta	0.020015	0.024207	0.008531
Rank	2	1	3

Table 11. Response table for S/N ratios smaller is better

S/N Ratios Smaller is better			
Level	Speed	Load	RHA
1	41.12	42.67	33.93
2	35.30	34.73	35.44
3	31.39	30.41	38.45
Delta	9.74	12.26	4.52
Rank	2	1	3

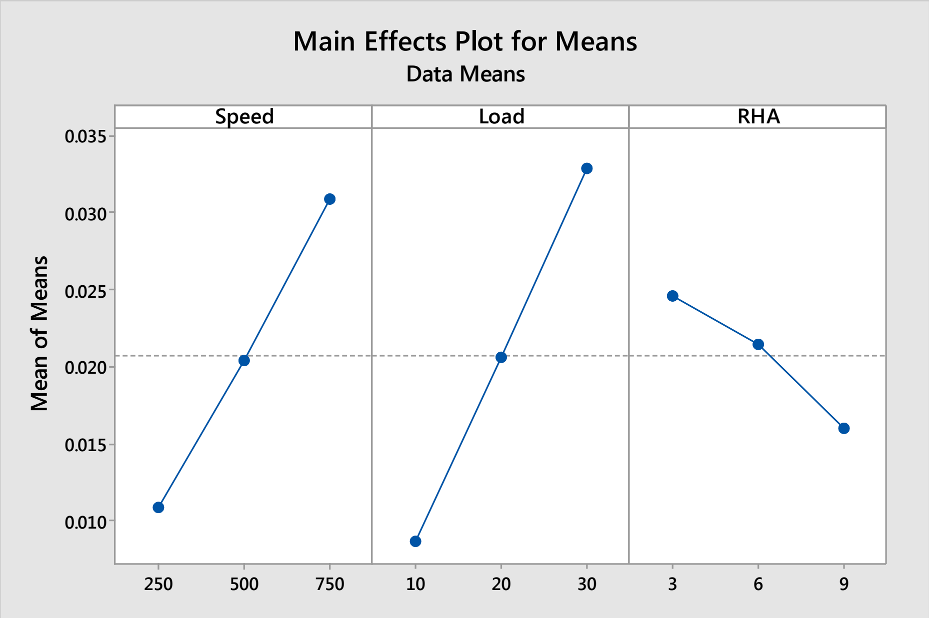

Fig. 4. Main Effects plot for Means of Means

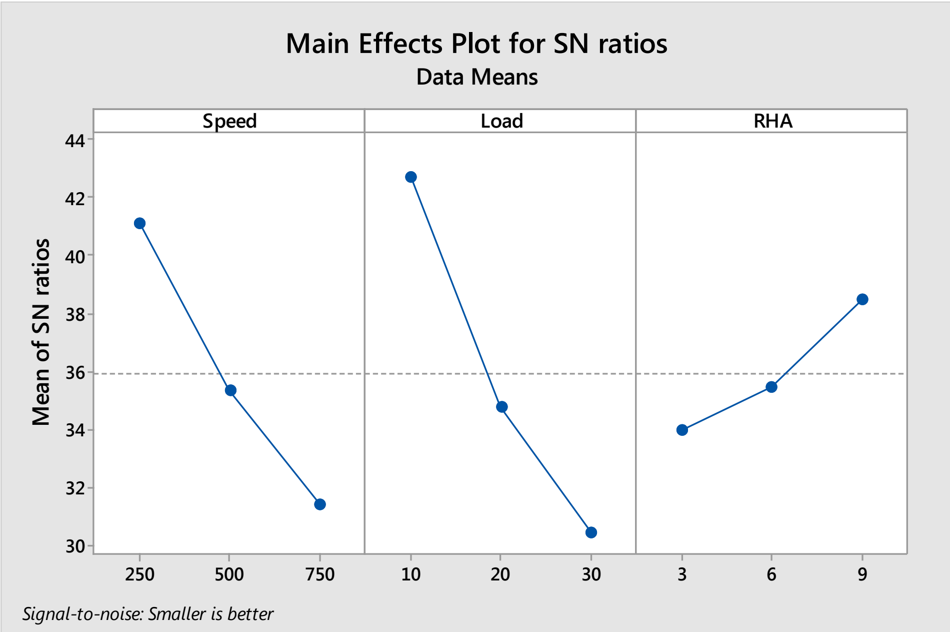

Fig. 5. Main Effects plot for Data SN ratio

Figures 4 and 5 main effects plot for mean and S/N ratio, each factor at different levels consisting of the maximum value of S/N ratio represents the significant level. The results indicate the maximum S/N ratio value is achieved by Speed (N) at level 1. Load (L) and wt.

% of RHA are at level 1 and Level 3 respectively. For Least wear, the ideal combination for experimentation is N1W1RHA3 (i.e., Speed= 250 rpm, Load = 10 N, wt. % of RHA = 9%).

Analysis of variance for wear. Variance test analysis is conducted to know the critical values which contribute largely to wear loss, and the interaction result on the hybrid composite samples along with the percent influence of each feature and factors interaction on ADC12 Aluminum Alloy-B_4C-RHA. Table 12 below indicates that the very critical parameter is Sliding speed (N) with the maximum contribution of 35.17%, along with Load (L) factor and wt. % of RHA whose contribution is 51.41% and 6.55% respectively towards hybrid composite specimen's wear loss. Among factors interactions, significant factors were speed (N) and load (S), have a contribution of 5.65 %.

Table 12. Analysis of variance for means

Source	DF	Seq SS	Adj MS	F Value	Contribution (%)
Speed	2	0.001804	0.000902	2470.37	35.17
Load	2	0.002637	0.001318	3610.65	51.41
RHA	2	0.000336	0.000168	459.83	6.55
Speed*Load	4	0.000290	0.000073	198.58	5.65
Speed*RHA	4	0.000028	0.000007	19.26	0.55
Load*RHA	4	0.000031	0.000008	21.38	0.60
Error	8	0.000003	0.000000		0.06
Total	26	0.005129			100.00

Confirmation test. For validation of analysis results, the regression technique was used. Using this technique, the relationship between the factors-interacting factors also output variable as a fitted equation to observed results.

Table 13. Analysis of variance for S/N ratio

Source	DF	Seq SS	Adj MS	F Value	P-value
Regression	6	1210.07	201.678	134.88	0.000
Speed	1	39.87	38.866	25.99	0.000
Load	1	50.39	50.390	33.70	0.000
RHA	1	30.20	30.201	20.20	0.000
Speed*Load	1	5.63	5.634	3.77	0.066
Speed*RHA	1	2.66	2.656	1.78	0.198
Load*RHA	1	6.47	6.474	4.33	0.051
Error	20	29.90	1.495		
Total	26	1239.97			

Table 13 depicts the analysis of variance for S/N ratio values used in developing the regression equation for the critical and interacting factors which resulted from the analysis of variance. Thus, the equation for S/N ratios obtained from regression analysis is

$$\mathrm{S/N\ Ratio} = 51.34 - 0.02119(\mathrm{S}) - 0.603(\mathrm{L}) + 1.557(\mathrm{RHA}) + 0.000274 \times (\mathrm{S} \times \mathrm{L}) - 0.000627 \times (\mathrm{S} \times \mathrm{RHA}) - 0.0245 \times (\mathrm{L} \times \mathrm{RHA})$$

Table 14 below gives the validation of test results under ideal conditions. When we compare the different values of S/N ratio for both experimental wear loss and the one calculated using the regression equation it's just -1.715. Therefore, the calculated and experimental results for S/N ratio values very close to each other are having the least difference.

Table 14. Confirmation test results at optimum conditions

Sl. No.	Speed	Load	RHA	Wear (mm^3/m)	S/N Ratio	Regression equation S/N ratio	Difference
1	250	10	9	0.0022882	**52.8103**	51.09475	-1.71555

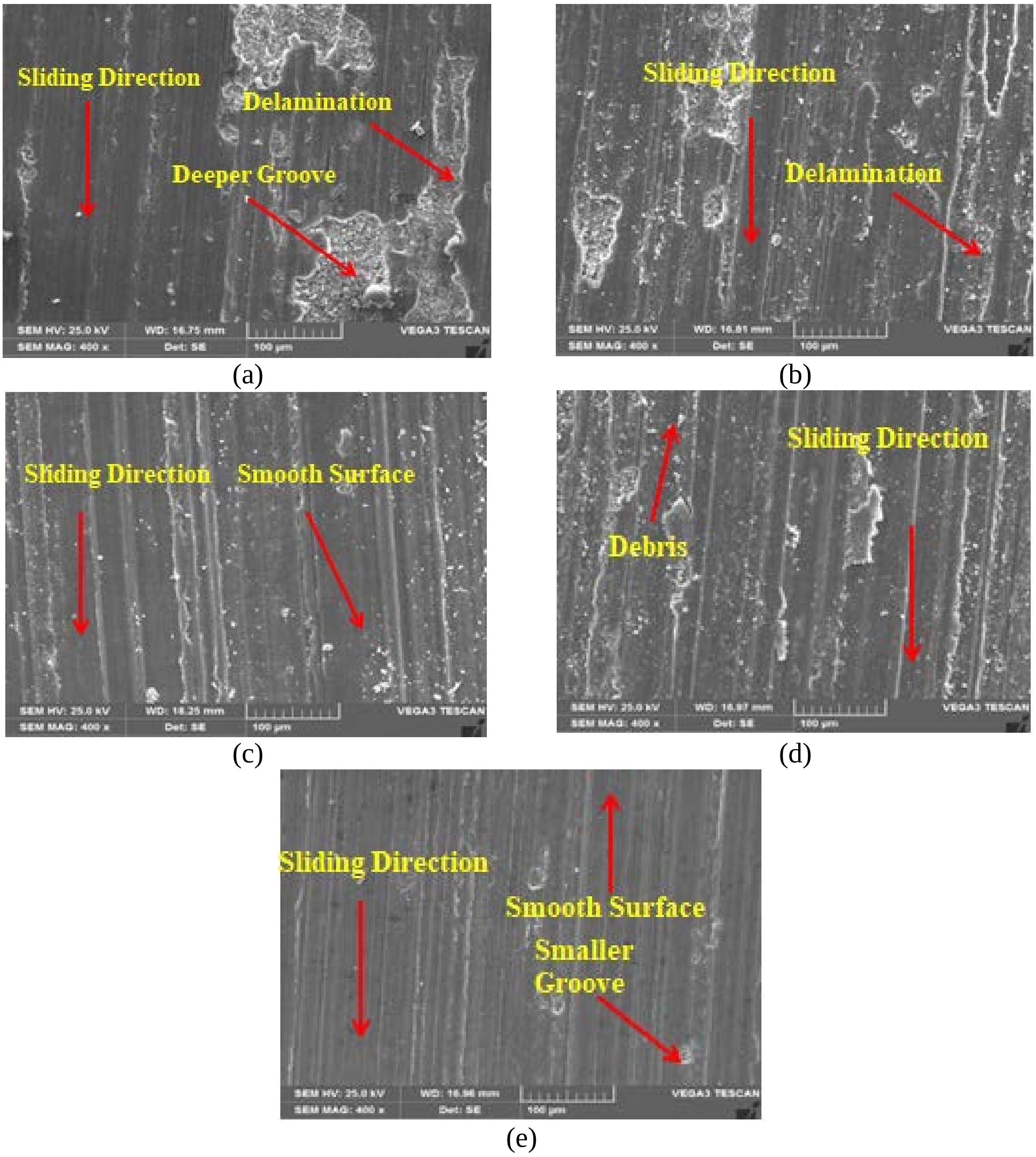

Fig. 6. Wear worn surfaces SEM images of (a) ADC12 alloy (b) ADC12-5 wt. % B_4C-3 wt. % of RHA (c) ADC12-5 wt. % B_4C-6 wt. % of RHA (d) ADC12-5 wt. % B_4C-9wt. % of RHA (e) ADC12-5 wt. % B_4C-12 wt. % of RHA composites

Worn surface analysis. Figure 6 is addressing the wear surfaces of ADC12 composite, ADC12 with 5 wt. % B_4C and 3 wt. % RHA, ADC12 combination with 5 wt. % B_4C and 6 wt. % RHA, ADC12 composite with 5 wt. % B_4C and 9 wt. % RHA and ADC12 compound with 5 wt. % B_4C and 12 wt. % RHA composites at the most extreme speed of 750 rpm and greatest loading condition of 30 N for 1000 m sliding distance. It is important to consider the worn surface morphology of ADC12 and its B_4C and RHA particulates composites as it shows the kind of wear the materials with various creations have gone through. During sliding, the ADC12 composite network is milder than the scouring circle material and consequently shows the thick progression of aluminum lattice, which is a pin causing plastic disfigurement of the example surface, bringing about high material misfortune [15,16]. As shown in Fig. 6 (a), the ragged surface of ADC12 compound contains sections, small pits, and a broken oxide layer, all of which contributed to the extension of wear problems. Large grooved regions on the worn surface of the ADC12 alloy are visible in Fig. 6 (a). Deeper adhesive grooves in ADC12 alloy, cracks on the worn surface, and scratches cause plastic deformation of unreinforced material. Continual wear grooves and a few damaged spots are visible, as shown in Fig. 6 (a). The frictional heat has softened the ADC12 alloy matrix, as evidenced by a large adhesive groove. More material was lost in those spots because they were chipped away under a heavier load and faster speed and over a longer sliding distance. In as-cast ADC12 alloy, the adhesive wear is most noticeable in the wide or larger delaminated region.

Lesser depressions and scores may be seen in Fig. 6 (b-e), indicating that the area is protected from wear. Figure 6 (b-e) shows the parallel groove which indicates the abrasive wear as formed by the intrusion of the hard boron carbide and RHA particles into a smooth surface. The scored grooves formed on the track disc in addition to the impact of the wear-hardened deposits. The presence of B_4C and RHA particles in the ADC12 alloy acts as a barrier for plastic deformation during the wear process. These particles are hard in nature which contributes a reduction in material loss during wear tests. Fig. 6 (e) is showing the worn surface of ADC12 alloy with 5 wt.% of B_4C and 12 wt.% of RHA particle reinforced composites. The worn surface is smooth due to the presence of hard particles; very small groves are visible on the surface.

5. Conclusions

ADC12 alloy with 5 wt. % of constant B_4C particles and 3, 6, 9, and 12 varying wt. % of RHA particles reinforced hybrid composites were prepared by the stir cast method. Scanning electron micrographs indicated the through the distribution of dual particles in the ADC12 alloy. From the Taguchi analysis and wear experimentation ofADC12 Aluminum Alloy-B_4C-RHA Composite samples, the following conclusions were drawn.

- The wear characteristics of ADC12 Aluminum Alloy-B_4C-RHA composites were studied by Taguchi technique.
- The ideal combination for experimentation with the least wear depth is known to be S1W1RHA3, i.e., Speed250 rpm, load 10 N, and Sliding wt.9% RHA. From the analysis of variance, the factors speed (N), Load (W), and wt. % RHA are found to affect the wear significantly.
- However, load (W) and speed (N) are important factors with a contribution of 86.58%. Among the interaction factors, Speed (S) * Load (W) and Speed * RHA has the contribution of 6.2% found to be the most significant interaction. Further, worn surface analysis exhibited various wear mechanisms under load and sliding velocity conditions.

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