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Research Article

Microstructure Study and Optimization of Hardness and Tensile Strength of AW2024/B4Cp Reinforced Composites Through Linear Regression

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ABSTRACT

The current research is focused on the production of AW2024/B_4C metal reinforced composite by using the liquid stir casting method. Ceramic particles armored composites are mainly used in engineering applications, which include aircraft, automotive, and marine fields. AW2024/B_4C composites are produced by changing wt.% of B_4C_p as 1.00%, 3.00% and 5.00%. The produced AW2024/B_4C composites are machined as per ASTM E8-16a, IS1500, and IS7739 standard test size and subjected to artificial ageing. The hardness and tensile strength of AW2024/B_4C composites were measured through a Brinell hardness tester and a universal testing machine, respectively. The microstructure of the prepared composite material was examined to determine the uniform distribution of reinforcement material. The highest hardness and tensile strength of AW2024/B_4C composites were measured and found to be 84.97 BHN and 273.82 N/mm^2 for AW2024/5%B_4C with 5 hrs. ageing duration. The results achieved reveal that both hardness as well as tensile strength increased by increasing the weight percentage of B_4C content. L_9 standard orthogonal display was espoused to investigate the best parameter and also to authenticate the experimental test results. Further, a fracture study was done through SEM images to determine the mode of fracture.

1. Introduction

Materials play a substantial role in engineering applications because of their superior mechanical properties and wear characteristics under different conditions. In the present industry demand, composite materials will meet the specific application due to their lightweight, lower cost, and superior functionality. Aluminum alloys will have a number of physical properties and mechanical characteristics that make them attractive for automotive components; however, they show very meager resistance to sliding motion and wear [1]. Composites generally perform well in applications such as dry sliding conditions to enhance their wear performance. In metal matrix composites, Aluminum alloys are widely selected as base metal due to their higher strength, light weight, resistance to environmental conditions, etc. [2]. A study on Al6061/SiC/B_4C hybrid composite is fabricated by using the stir casting

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route. The mechanical characterization and their internal arrangements were deliberated using SEM images [3]. Research work on Al7075/SiC particle reinforced composites [4] and conveyed that SiC reinforced particles are homogeneously dispersed in the Al6061 alloy with less particle agglomeration. However, the distribution of SiC was reduced with an increase in the weight content of the silicon carbide particle size. Evaluated the hybrid composites of Al7075/B_4C/coconut shell fly ash, exhibiting maximum hardness for 12 wt.% of B_4C and 3 wt.% of coconut shell fly ash. Reinforcement particles that absorb the impact load during the impact test will act as an obstacle against crack propagation, resisting fracture [5]. Research work on Al6061-Al_2O_3-SiC hybrid composite [6], suitable process parameters are acknowledged for COF and wear rate using standard L_9 OA. ANOVA was also adopted to find out the percentage involvement of each factor that influences on wear rate and COF of hybrid composites. Explored a research study on SiC reinforced Al7075 alloy composite and Al7075/TiB_2 composite by stir casting process. The authors conveyed that when assessed with SiC and TiB_2 reinforced composites, unreinforced aluminium 7075 alloy exhibited less hardness and strength. Further, higher hardness of 4.93% and 3.29% of higher strength are obtained for the titanium diboride reinforced composite when matched to the SiC reinforced composite [7]. Reported that the mass density of Al2024/ B_4C composite reduced with the increase in weight content of B_4C, the motive is to existence of voids in Al-Cu alloy. Unreinforced Al2024 alloy exhibits ductile kind of failure; however, an increase in the content of B_4C reinforcement in soft Al2024 alloy resulted gradual change in failure type, i.e, ductile failure to brittle failure. It was explored from SEM monographs that for 5 wt.% of B_4C particles on AW2024 alloy, the tensile strength was not significant, which is owing to brittle tearing [8-9]. The effort has been made on a nickel alloy base hybrid composite with Al_2O_3 and TiO_2 reinforcement through the sand mold casting method to evaluate the microstructure and thermal properties. Reinforcement elements are scattered in the nickel alloy matrix along the length of the grain boundary, and fine precipitates are observed [10]. Investigative work on Al7075/SiC/Gr. A hybrid composite uniformly distributed reinforcement was observed throughout the matrix, which was achieved due to proper stirring. Further, Taguchi's technique was adopted by using L_{16} OA with four levels to recognize the contribution of reinforcements on ductility and yield strength, followed by the authentication of the experimental results by regression equations. The prepared hybrid composites represented the increase in tensile strength and hardness when linked to unreinforced material alone due to the acceptable quality bonding between the matrix alloy and the reinforcement [11-12]. Notable work carried out on Al2024/B_4C composite by varying different B_4C particle sizes in weight percentage by the stir-cast fabrication method. It was recounted that the ductility of the composite declined with the content of wt.% of B_4C particles. However, the mechanical strength of prepared composites was seen to be enhanced. Further, fracture study reveals that the existence of B_4C_p was observed with a small dimple structure resulting in ductile fracture [13]. Examination on the hardness of the fabricated hybrid composite was increased with the addition of silicon carbide for a constant 2.5% of Al_2O_3 in Al7075 alloy. However, material loss was decreased with an increase in silicon carbide in Al7075 alloy. For wear specimens, SEM images reveal that higher hard particles in wt.% on the A17075 alloy contributed to deeper grooves and show sufficient bonding between alloy and reinforcement [14]. An attempt was been carried out on Ni-Cu alloy reinforced with Al_2O_3 & TiO_2 through sand mould casting route and confirmed that a fairly uniform distribution was seen in Ni-Cu alloy with a lower porosity level. By addition of reinforcements in Ni-Cu alloy exhibits the dendritic arrangement in the formed hybrid composite. When the normal load on Ni-Cu alloy reinforced by Al_2O_3 and TiO_2 increased wear rate also increased. An investigation on Al-Ni based alloy reinforced by two reinforcements, namely Al_2O_3 and e-glass particles, in wt.% by adopting the stir casting method. It was stated that theoretical density and experimental density show slight variations in results for all compositions. However, theoretical density results show moderately higher values than the experimental values, and the porosity level increased in the hybrid composite with a gradual increase in reinforcements [15-16]. Emphasis has been placed on the Al/Cu/Brass multilayered composite developed by Accumulative Roll Bonding (ARB) process and concluded that fracture occurred in the brass layer after the second cycle onwards, which occurs occurred to the accumulation of plastic strain in the prepared test sample during ARB cycles [17]. The effort has been made on the behavior of 7085 Al alloy at different quenching rates experimentally through microstructure characterization, thermodynamic calculation, and electrical conductivity test [18]. Investigation on Al-Cu based composite by stir casting choice was conducted to know the experimental hardness and validated through linear regression and machine learning method [19]. Work on

SiC/HFC-based ceramics was reported to further improve functional properties and to determine the chance and importance of boron particles in the SiC/HfC system [20]. Unidirectional molybdenum and tungsten fiber reinforced Silicon carbide nitride ceramic-based composite were produced by adopting the polymer infiltration technique, and reported an average of UTS is 2780 MPa for mono fiber tensile test for tungsten fiber and 1647 MPa for molybdenum fiber [21]. Based on the fact and the above research findings by various investigators, the current research article aims to develop a sound AW2024/B_4C composite through the die casting method. To estimate the hardness as well as tensile strength of the formed composite material experimentally, and also to authenticate the experimental test results by regression analysis. Standard array tables have been used to determine the optimal parameters for better hardness properties and tensile strength. Optical images study and SEM examination of fracture tensile specimens were also discussed and reported in this research article.

2. Materials and Production of Composites

In this section selection of material, fabrication, machining, heat-treatment technique used, and standard orthogonal array used were discussed.

2.1. Selection of Matrix and Reinforcement Material

The existing research study on copper-based aluminum alloy has been selected as base/matrix material, which has been procured from Fenfe Metallurgical, Bangalore, along with 3 different B_4C particle sizes as reinforcement. Figure 1 indicates the AW2024 alloy in the Ingot form as received from the Fenfe metallurgical, Bangalore. Figure 2 (a), (b), and (c) represent the SEM images of B_4C particles with an average particle size of 186.16 μm, 96.82 μm, and 69.78 μm for 100-mesh size, 200-mesh size, and 300-mesh size, respectively.

Fig. 1. Ingots of AW2024 matrix alloy.

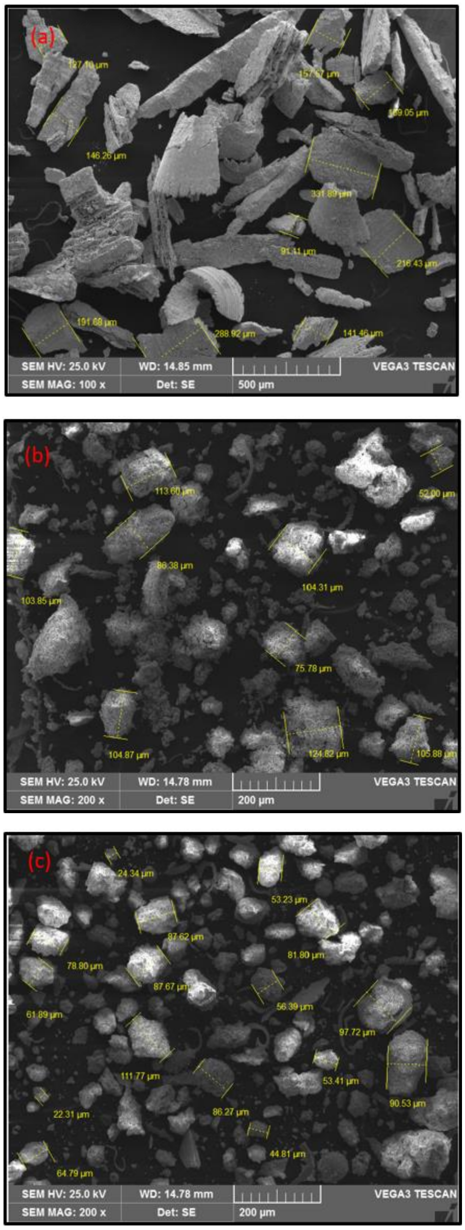

Fig. 2. SEM photograph of B_4C particles. (a) 100 mesh-size, (b) 200 mesh-size, (c) 300 mesh-size.

Table 1. Elemental composition of AW2024 alloy.

Element	AW	Cu	Mg	Fe	Si	Zn	V
Wt.%	92.82	4.48	0.81	0.42	0.16	0.15	0.05

Table 2. Properties of B_4C particle.

Property	Values
Density (g/cm^3)	2.55
Tensile Strength (MPa)	261
Melting Temperature (°C)	2,763
Specific gravity (g/cm^2)	2.52
Knoop Hardness	3770

2.2. Preparation of Composites

The required quantity of AW2024 matrix alloy is calculated based on the size of the casting die and composition as represented in Table 3 (a-c). The as-received AW2024 matrix alloy is cut by using a power hacksaw machine and placed inside the graphite crucible. Pre-heated crucible along with the calculated AW2024 matrix alloy is kept inside the electric furnace as shown in Figure 3. The melting furnace is kept to a pre-determined temperature of 750°C, and AW2024 alloy is melted via a heat transfer process through the heated walls of the graphite crucible. After melting AW2024 alloy in a graphite crucible, pre-heated B_4C particles (350°C) were added into the molten AW2024 matrix alloy, and effective stirring was carried out at 550 rpm for about 8 min to attain the dispersion of boron-carbide particles uniformly throughout the AW2024 matrix. A degassing tablet is added to the molten mixture (matrix and reinforcement) to eliminate the entrapped air to prevent the blowholes and porosity, thereby enhancing the strength of the formed composites.

Table 3 Composition of prepared AW2024/B_4C composite and its notation

(a). For a mesh size of 100 B_4C

Composition/ Heat treatment condition	AW2024 + 0% B_4C (As Cat)	AW2024 + 1.00% B_4C	AW2024 + 3.00% B_4C	AW2024 + 5.00% B_4C
Non-heat-treated	S000	S110	S130	S150
1hr. ageing duration	S001	S111	S131	S151
3hrs. ageing duration	S003	S113	S133	S153
5hrs. ageing duration	S005	S115	S135	S155

(b). For a mesh size of 200 B4C

Composition/ Heat treatment condition	AW2024 + 1.00% B_4C	AW2024 + 3.00% B_4C	AW2024 + 5.00% B_4C
Non-heat-treated	S210	S230	S250
1hr. ageing duration	S211	S231	S251
3hrs. ageing duration	S213	S233	S253
5hrs. ageing duration	S215	S235	S255

(c). For a mesh size of 300 B4C

Composition/ Heat treatment condition	AW2024 + 1.00% B_4C	AW2024 + 3.00% B_4C	AW2024 + 5.00% B_4C
Non-heat-treated	S310	S330	S350
1hr. ageing duration	S311	S331	S351
3hrs. ageing duration	S313	S333	S353
5hrs. ageing duration	S315	S335	S355

The notation indicated in Table 3 (a-c) has the following illustration:

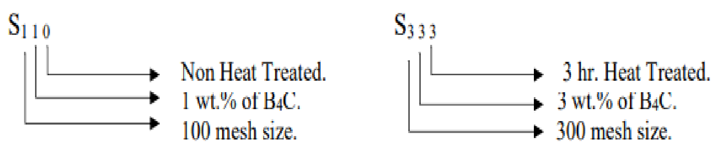

Fig. 3. Experimental setup for HMMC's: (a) Electric furnace, (b) Poring a hybrid composite mixture

2.3. Machining of Shaped Composite Material and Heat Treatment

The cast AW2024/B_4C composites are cut to a required length and turned by considering a traditional lathe machine tool to prepare test specimens as per the acceptance standard size. Tungsten carbide cutting tools with a 1mm depth of cut and, 0.5mm/min feed rate are used to prepare the test specimen and to carry out heat treatment. The photographs of tensile, hardness, and microstructure test samples are machined as per ASTM E8-16a, IS: 1500, and IS: 7739 and are represented in Figures 4, 5, and 6, respectively.

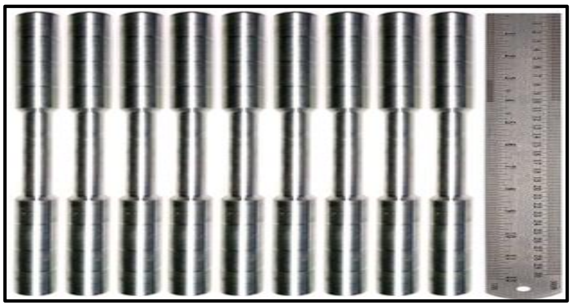

Fig. 4. AW-2024/B_4C composite -Tensile test samples

Fig. 5. AW-2024/B_4C composite - Hardness test samples.

Fig. 6. AW-2024/B_4C composite - Microstructure test samples.

The machined test samples are exposed to the heat-treatment process in 2 different stages:

- Stage1: Solutionzing

  The machined test samples are heated for 24 hrs. at a constant temperature of 520 °C, and the test samples are quenched in water media till the test specimens attain room temperature.

- Stage 2: Artificial Ageing

  After stage 1, the test specimens were kept at a constant temperature of 175°C for a holding period of 1 hr., 3 hrs., and 5 hrs. for the particular composition. Heat treatment for the machined test specimens is illustrated schematically in Figure 7. Figure 8 (a) and (b) represent the heat-treatment furnace and water-quenching setup used for this study.

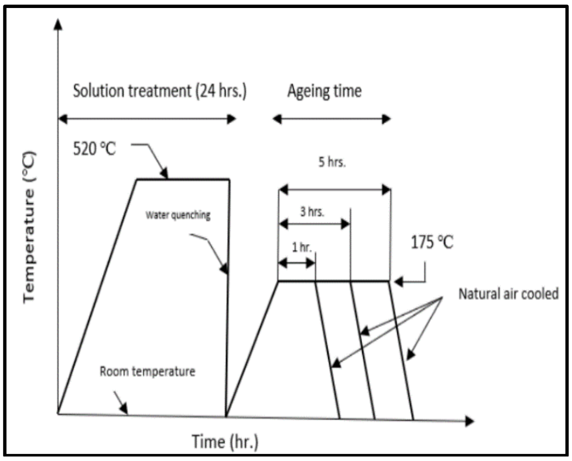

Fig. 7. Artificial heat treatment plot for AW2024/B_4C composite.

Fig. 8. (a) Heating furnace equipment

Fig. 8. (b) Quenching setup

2.4. Methodology Adopted

In the current investigation, a design-of-experiment was used by selecting the L_9 standard array table for optimization of hardness as well as tensile strength of AW2024/ B_4C composite material. Further, analysis of variance and regression equations are generated to evaluate the contribution of each variable in percentage and also to authenticate the experimental test results. The variable and their level adopted for the present study are represented in Table 4.

Table 4. Input variables and their levels used

		Levels		
Sl. No.	Input variable	A	B	C
1	B_4C (wt.%)	1	3	5
2	Ageing duration (hrs.)	1	3	5
3	Mesh size	100	200	300

3. Results and Discussions

In this part, a study on microstructure, hardness, tensile strength, optimization, analysis of variance, validation of experimental results using linear regression (LR) equation, and SEM images of AW2024/B_4C composite has been deliberated.

3.1. Microstructure Study of AW2024/B4C Composite

Figure 9. (a) demonstrates the microstructure images of AW2024 alloy without heat treatment, and it is seen from the image that a larger grain size is associated with a larger grain boundary. The larger grain is due to the occurrence of porosity and the insufficient use of the degassing tablet during the production of AW2024 alloy. Figure 9. (b-d) shows the microstructure photograph of AW2024/B_4C composite with different heat-treatment periods. With the increase in heat-treatment period from 1 hr. to 5 hrs., excellent bonding has been seen between AW2024 base and B_4C particle. The microstructure looks like a refined grain structure with sound bonding leading to enhanced hardness and yield strength when assessed with the AW2024 matrix. Porosity, blowholes, and voids have significantly vanished, which is attributed to the worthy precipitation of B_4C_p in the soft AW2024 matrix alloy. Due to sufficient duration of heat-treatment and pre-heated $B_4C_{p,}$ in soft AW2024 alloy exhibits uniform distribution, which leads to enhanced mechanical properties. These results are in line with the previous findings by P. Subramanya Reddy et al [3].

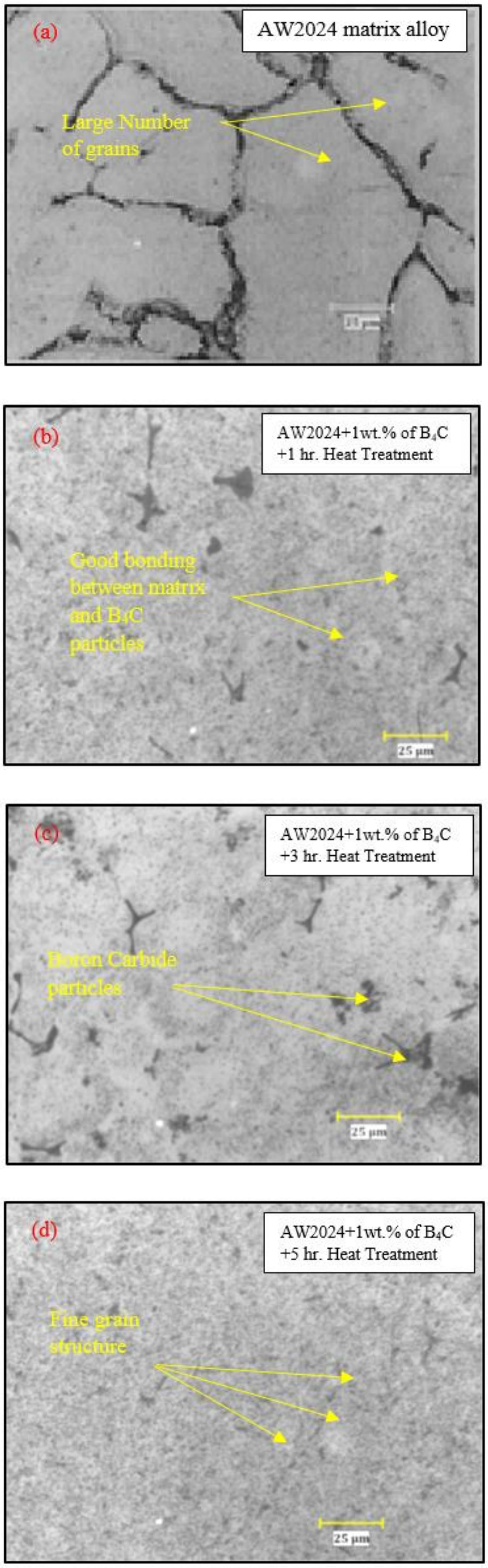

Fig. 9. (a-d) Microstructure photograph of AW2024/B_4C composite for different heat treatment durations

3.2. Hardness of prepared AW2024/ B_4C composite

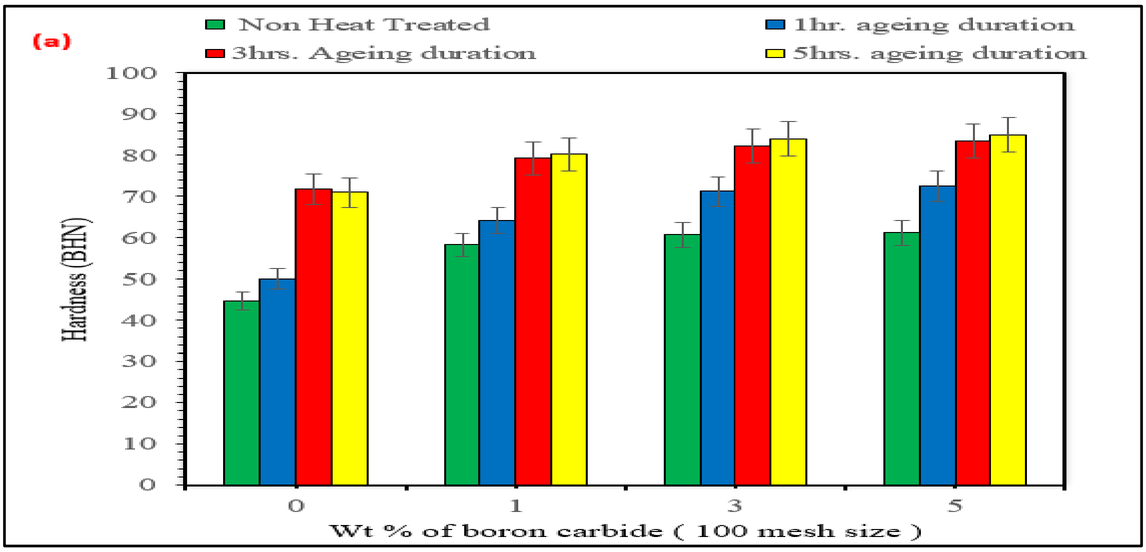

Fig. 10. (a) Plot of Hardness for different AW2024/B_4C composites (100 mesh size of B_4C)

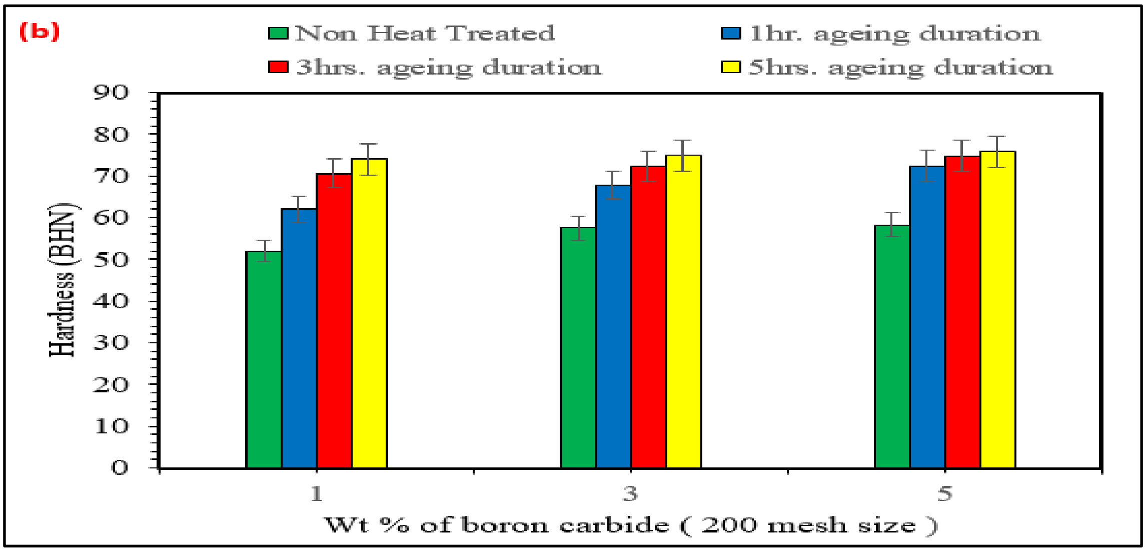

Fig. 10. (b) Plot of Hardness for different AW2024/B_4C composites (200 mesh size of B_4C)

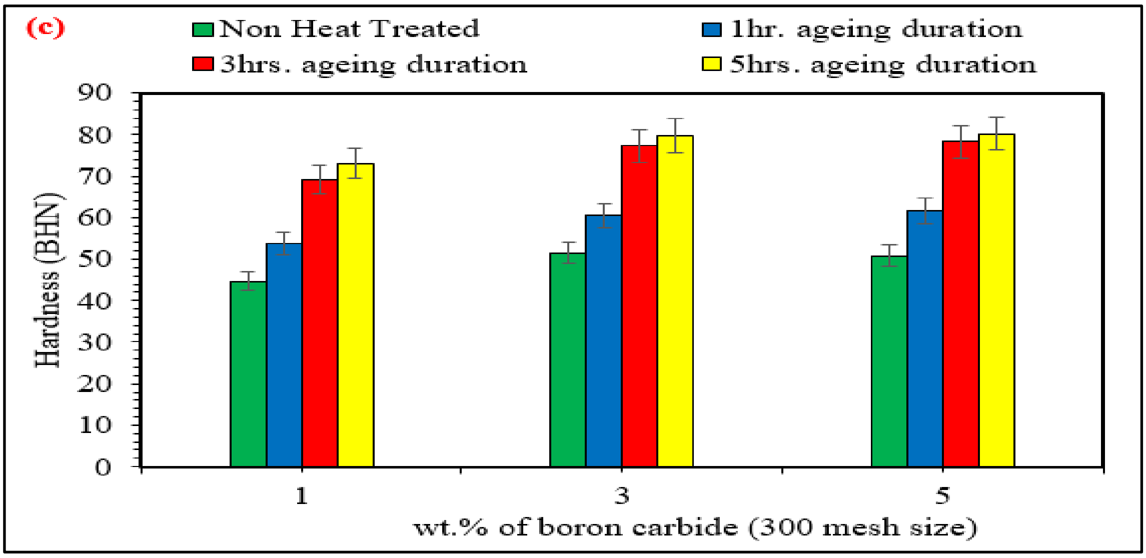

Fig. 10. (c) Plot of Hardness for different AW2024/B_4C composites (300 mesh size of B_4C)

Evaluation of Brinell Hardness (BH) number for unreinforced and reinforced AW2024-based composites with heat treatment is displayed in Figure 10. (a-c). The BH number of AW2024/ B_4C composite increased gradually from 1 weight percentage to 5 wt.% of B_4C, this enhancement might be the existence of hard ceramic particles in the soft AW2024 matrix alloy. It is seen that the BH number of AW-2024 alloy improved with an increase in heat treatment duration from 1hr. to 3 hours. However, for 5hrs heat treatment hardness value is slightly reduced. The percentage enhancement in hardness is 60.45%. Among various mesh sizes of B_4C particles in soft AW2024 matrix alloy, the 100 mesh size particle reinforced composite exhibits greater hardness number, which might be the fine-tuning of the grain structure of B_4C particles, which have restricted the indenter from penetrating into the prepared composite. Percentage enhancement in hardness number is seen to be 90.04% for AW2024/5 wt.% of B_4C/5 hrs. of heat treatment duration when matched with AW2024 matrix alloy without heat treatment.

3.3. AW2024/B4C Composite - Tensile Strength

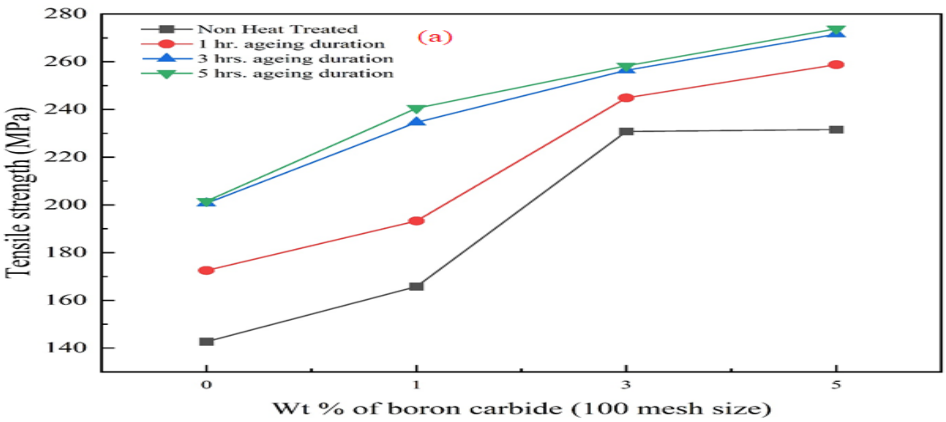

Fig. 11. (a) Tensile strength plot for different AW2024/B_4C composites (100 mesh-size of B_4C)

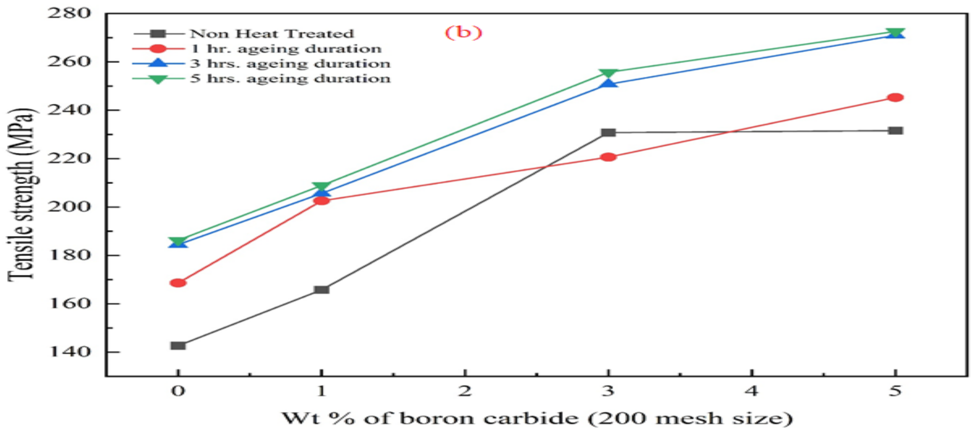

Fig. 11. (b) Tensile strength plot for different AW2024/B_4C composites (200 mesh-size of B_4C)

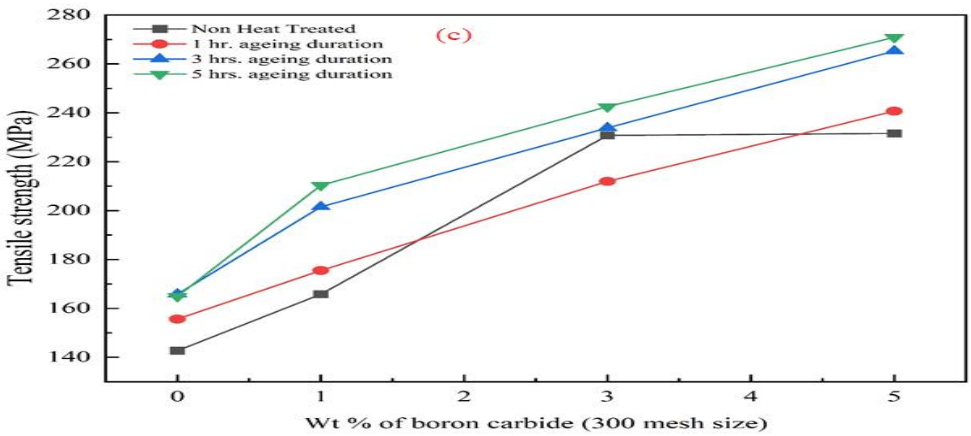

Fig. 11. (c) Tensile strength plot for different AW2024/B_4C composites (300 mesh-size of B_4C)

Figure 11. (a-c) depicts the variation of tensile strength of AW2024/boron-carbide reinforced composite material by changing wt.% of boron-carbide particles for different mesh sizes of B_4C particles. As the percentage of boron-carbide particles increases in soft AW2024 alloy, an increase in tensile strength was noticed, which might be the significant bonding between AW2024 matrix and boron-carbide reinforcement. The uniform spreading of reinforcement throughout the matrix has contributed to increasing the tensile strength. When compared, the unreinforced, reinforced AW2024 alloys show better tensile strength; the reason might be the occurrence of hard carbide particles. Compared to three different mesh sizes of B_4C particles, 100 mesh size particles on AW2024 alloy exhibit noteworthy tensile strength, which is attributed to uniform particle distribution and size of the B_4C particles. The percentage enhancement in the tensile strength is 91.91% when matched with AW2024 alloy and AW2024/5% B_4C/5 hrs. of heat-treated composite specimen. However, with an increase in mesh-size of B_4C from 100 to 300, there is not much significant fall in tensile-strength value, this may be due to the impact of the heat-treatment process, which has minimized the porosity or which has made the composite harder.

3.4. Optimization of BH Number and Tensile Strength of AW2024/B4C Composite

It is perceived from Figure 12. (a) the optimal levels for BH number of AW2024/B_4C reinforced composite is A2B3C1 i.e 3 wt.% of B_4C, 5 hours of ageing period and 100 mesh-size of B_4C. However, for the tensile strength of AW2024/B_4C reinforced composite, the optimum levels are A3B3C1. i.e, 5 wt.% of B_4C, 5 hours of ageing duration, and 100 mesh-size of B_4C as seen in Figure 12. (b).

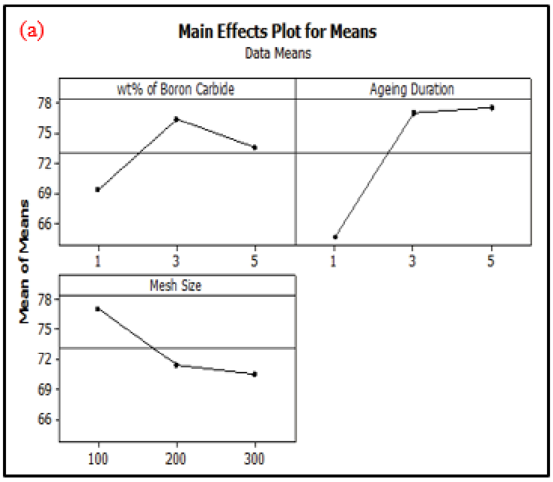

Fig. 12. (a) Optimization of the BH number of AW2024/B_4C reinforced composite.

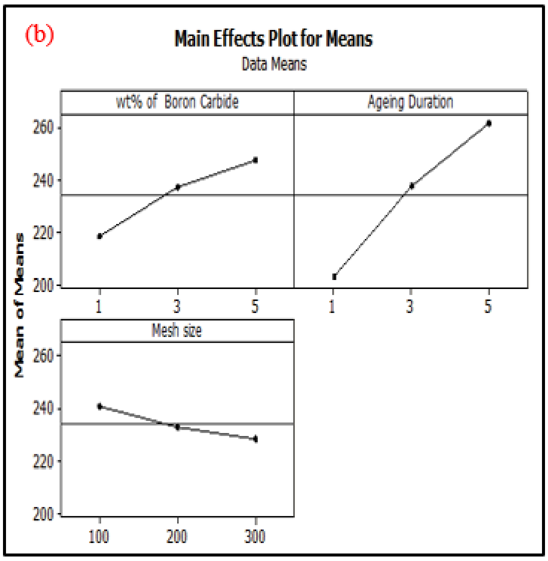

Fig. 12. (b) Optimization of Tensile strength of AW2024/B_4C reinforced composite.

Table 5 (a). Response / Output table for optimization for hardness of AW2024/B_4C reinforced composite

Level	B4C	Ageing period	Mesh-size
1	69.3	64.53	77.2
2	76.35	77.11	71.44
3	73.62	77.63	70.63
Delta	7.05	13.1	6.57
Rank	2	1	3

Table 5 (b). Response/output table for optimization for Tensile strength of AW2024/B_4C reinforced composite

Level	B4C	Ageing period	Mesh-size
1	218.2	203.1	241
2	237	237.6	232.9
3	247.1	261.6	228.3
Delta	28.9	58.5	12.8
Rank	2	1	3

3.5. ANOVA for BH number and Tensile Strength of AW2024/B4C Composite

Table 6. ANOVA table for the BH number of AW2024/B_4C reinforced composite

Factors	Wt. % of B_4C (A)	Ageing Period (B)	Mesh-Size (C)	error	Total
Seq. SS	75.883	329.966	76.966	12.711	495.526
Adj. SS	75.883	329.966	76.966	12.711	495.526
Adj. MS	37.942	164.983	38.483	6.356	247.764
F - Value	5.97	25.96	6.05		
P - Value	0.143	0.037	0.142		
DF	2	2	2	2	8
% Contribution	15.31	66.58	15.53		97.43
Rank	3	1	2		

Table 7. ANOVA table for tensile strength of AW2024/B_4C reinforced composite

Factors	Wt.% of B_4C (A)	Ageing period (B)	Mesh-Size (C)	error	Total
Seq. SS	898.15	4388.65	480.2	21.59	5788.58
Adj. SS	898.15	4388.65	480.2	21.59	5788.58
Adj. MS	449.08	2194.33	240.1	10.79	2894.3
F - Value	41.61	203.32	22.25		
P - Value	0.023	0.005	0.043		
DF	2	2	2	2	8
% Contribution	15.51	75.81	8.29		99.63
Rank	2	1	3		

The percentage influence for hardness of AW2024/B_4C reinforced composite is tabulated in Table 6, 66.58% for Ageing duration, 15.53% for mesh size, and 15.31% for wt. % of B_4C corresponds to P - P-P-value 0.143, which has meager influence on hardness. However, for the tensile strength of AW2024/B_4C reinforced composite, the chief contribution is 75.81% for the ageing period, followed by 15.51% of wt.% of B_4C and 8.29% for mesh size, which are computed in Table 7.

3.6. Regression Analysis for BH Number and Tensile Strength of AW2024/B4C Composite

Table 8. Assessment of experimental BH number and predicted BH number of AW2024/B_4C reinforced composite using regression analysis.

Trails	Wt.% of B_4C (A)	Ageing duration - hrs. (B)	Mesh Size (C)	Expt. hardness (BHN) (X)	Predicted Hardness (BHN) = 66.5953 + 1.08 A + 3.27417 B - 0.03285 C (Y)	error (%)
A1	1	1	100	64.21	67.66	5.37
A2	1	3	200	70.64	70.93	0.39
A3	1	5	300	73.04	74.19	1.57
A4	3	1	200	67.81	66.54	1.87
A5	3	3	300	77.27	69.80	9.65
A6	3	5	100	83.97	82.92	1.23
A7	5	1	300	61.57	65.41	6.23
A8	5	3	100	83.41	78.53	5.83
A9	5	5	200	75.87	81.80	7.8
					Avg. Error =	4.43%

Table 9. Assessment of experimental tensile-strength and predicted tensile-strength of AW2024/B_4C reinforced composite using regression analysis.

Trails	Wt.% of B_4C (A)	Ageing duration - hrs. (B)	Mesh Size (C)	Exp. Tensile strength (N/mm^2) (X)	Predicted Tensile strength (N/mm^2)= 194.139 + 6.08675 A + 13.4958 B - 0.0864517 C (Y)	Error (%)
A1	1	1	100	206.87	205.08	0.86
A2	1	3	200	220.6	223.42	1.27
A3	1	5	300	240.68	241.77	0.45
A4	3	1	200	205.65	208.60	1.43
A5	3	3	300	233.81	226.95	2.92
A6	3	5	100	271.57	271.23	0.12
A7	5	1	300	210.35	212.13	0.84
A8	5	3	100	258.271	256.41	0.71
A9	5	5	200	272.57	274.76	0.8
					Avg. Error =	1.04%

Predicted Hardness (BHN) = 66.5953 + 1.08 A + 3.27417 B - 0.03285 C……………………………….(1)

Predicted Tensile strength (N/mm^2) = 194.139 + 6.08675 A + 13.4958 B - 0.0864517 C……………………………………………..(2)

The experimental hardness for AW2024/B_4C reinforced composite and tensile strength of AW2024/B_4C reinforced composite are validated by comparing with the predicted values from the regression equation.

The percentage error for each trial is computed in the last column of Tables 8 and 9. It is seen that each experimental trial carried out as per the L_9 standard orthogonal array reflects that the outcomes of experimental values are sound within the acceptable limit. The average percentage of error for hardness and tensile strength was seen to be 4.43% and 1.04%. Hence, experimental hardness test results and tensile strength results are validated. The plots of experimental test values and predicted test values for hardness and tensile strength are drawn in Figure 13 (a) and (b). Table 10 shows the summary of the model with the R-squared value.

3.7. Model Summary for Hardness and Tensile Strength AW2024/B4C Composite

Table 10. Regression model summary

Parameter / Properties	Hardness	Tensile strength
S	2.52106	3.28523
R-Sq.	97.43%	99.63%
R-Sq. (adj.)	89.74%	98.51%

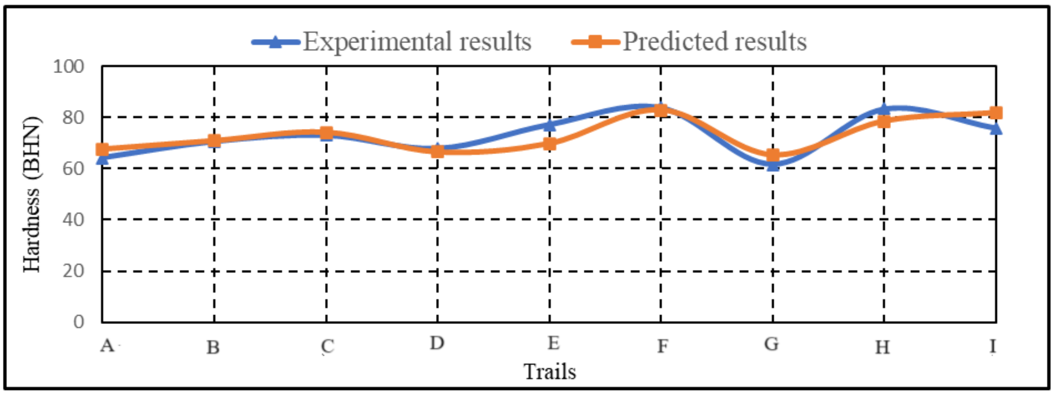

Fig. 13. (a) Graph of experimental hardness and predicted results of hardness for AW2024/B_4C composite.

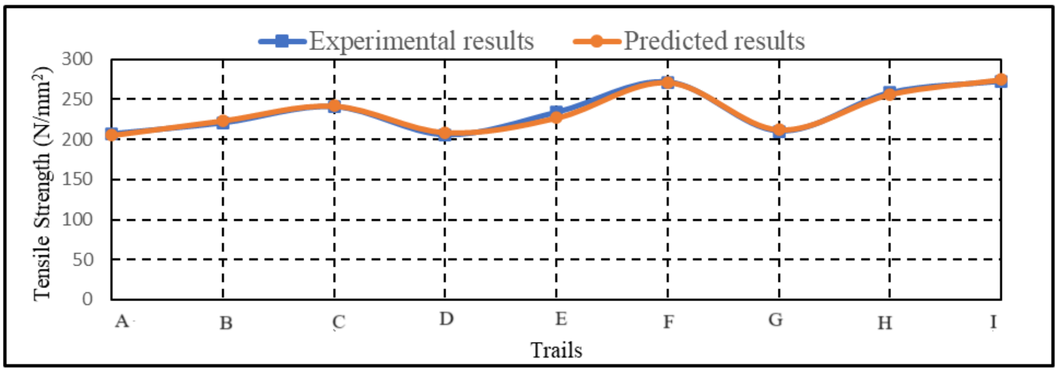

Fig. 13. (b). Graph of experimental and predicted results of tensile strength for AW2024/B_4C composite

3.8. Tensile Fracture Study of AW2024/B4C Reinforced Composite Material.

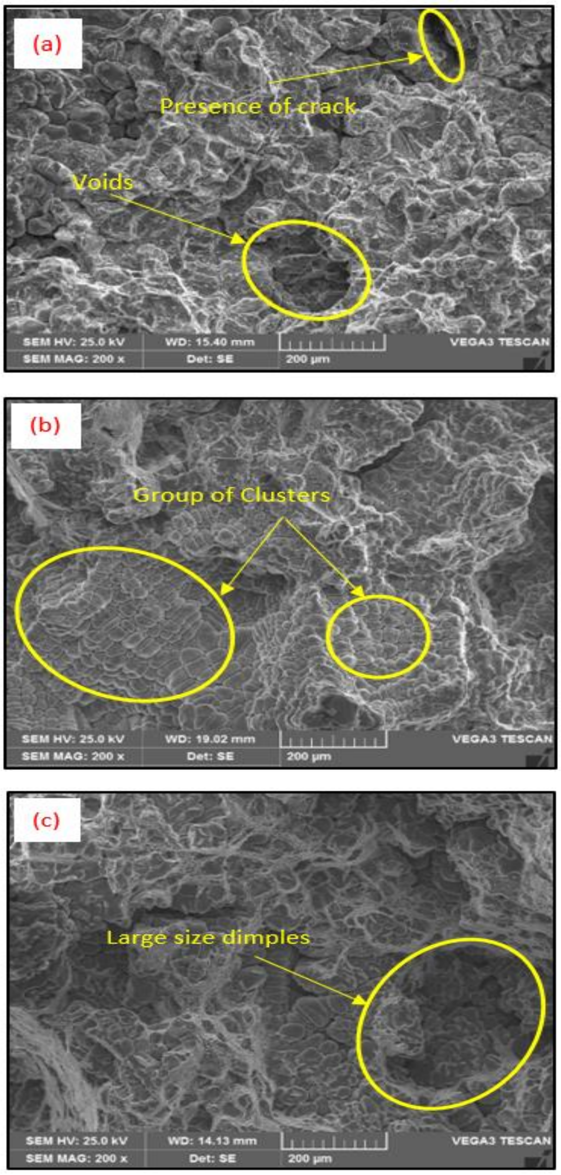

Fig. 14. Tensile fracture SEM images for (a) AW2024/3 wt.% B_4C reinforced composite (100 mesh-size), (b) AW2024/3 wt.% B_4C reinforced composite (200 mesh-size), (c) AW2024/3 wt.% B_4C reinforced composite (300 mesh-size)

Tensile fracture test specimens of AW2024/ 3wt.% of B_4C composite for different mesh sizes are represented in the Figure. 14 (a-c). It was observed that voids and cracks were present for AW2024/3 wt.% B_4C reinforced composite for 100 mesh-size B_4C_p, which leads to lesser tensile strength and hardness. Related kinds of results were obtained for Al6061/1 wt.% of SiC/1 wt.% of B_4C hybrid composite [3]. Rough grain arrangement and tightly packed reinforcement were observed, which attributed to a slight increase in hardness when compared to unreinforced AW2024 alloy, as shown in Figure 14. (a).

With the content of mesh-size of B_4C_p from 100 to 200 mesh size, the group of clusters was observed, which caused a greater number of grains with additional grain boundaries, which will restrict the flow of material plastically, leading to an increase in hardness and strength of the composite, as shown in Figure 14. (b).

Further, an increase in mesh-size of B_4C reinforced particle from 200 to 300 mesh-size on soft AW2024 alloy exhibits a hard, dark dimple arrangement with tightly packed with the matrix alloy, leading to further enhancement of hardness and tensile-strength, causing ductile type of failure as represented in Figure 14. (c).

The reason for the enhancement in hardness and higher tensile strength of the formed composite is due to the pre-heated B_4C reinforced particles, which were introduced during the casting process, reinforcement particle size, shape, effective stirring speed, and proper pouring temperature during production of the cast specimen.

4. Concluding Remarks

A complete examination has been done on AW2024 alloy armored with varying B_4C particles with 3 different mesh sizes, followed by heat treatment in 2 different stages. The following outcomes have been drawn:

- A high-quality casting process was successfully carried out by incorporating different mesh sizes of B4C reinforced particles on soft AW2024 alloy by using stir stir-cast direction.
- With a gradual increase in Wt.% of B_4Cp in the soft AW2024 alloy, the tensile strength as well as hardness were found to increase by 47.89% and 47.38%, respectively, for 5 weight percentage of B_4C_p.
- Compared to the untreated composite, the heat-treated composite reveals potential improvement in hardness as well as the tensile-strength value, which is due to the strengthening mechanism during the heat-treatment process.
- Optimal process factors for hardness of AW2024/B_4C reinforced composite are 3 weight percentage of B_4C, 5 hours heat treatment and 100 mesh-size. However, for tensile strength, the optimal process factor is 5 wt.% of B_4C, 5 hours heat treatment, and 100 mesh size.
- The regression analysis equation shows average error was found to be 4.43% and 1.04% for hardness as well as tensile strength of AW2024/B4C composite.
- Tensile fracture specimens show rough dimple arrangement, clustering of grains resulting ductile type of failure.

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Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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