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Research Article

Artificial Intelligence Optimization of Turning Parameters of Nanoparticle-Reinforced P/M Alloy Tool

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In this research, the powder metallurgy- (P/M-) based metal matrix composites were prepared to compose the machinability characteristics. Therefore, the Al2024 and boron carbide (B_4C) were the base and strengthened reinforcements. During the powder metallurgy process, weight fractions of boron carbide are 4, 8, and 12%; the compaction pressure is 300 to 400 MPa, and the sintering temperature is 420 to 540°C, respectively. These parameters were planned with Taguchi L9 array for achieving the proper design. After the processing, composite specimens were utilized to conduct the turning process. For all the nine specimens, depth of cut, speed, and feed rates were maintained constant with optimal parameters. The surface roughness and material removal rate responses are successfully achieved in the optimal turning parameters. Then, the artificial neural network (ANN) model was implemented to analyze the predicted values with back propagation algorithm. In this ANN, three input layers, 6 and 4 hidden layers, and two outputs were created as per the design. Finally, the minimized surface roughness and maximized material removal rate were achieved at the process parameters like 8 wt. % of boron carbide, 300 MPa of compaction pressure, and 480°C of sintering temperature. All the predicted values are slightly maximum than the experimental values.

1. Introduction

The superior property-based aluminium alloys are treated with various engineering applications in the automobile, ship building, airliner industries, and welding industries. The aluminium alloy was the chosen as the good compact material in different alloys [1]. Since it has exceptional engineering properties such as low density, corrosion resistance, heat exchanger, wear resistance, and good conduction of thermal and electricity. Aluminium is copious material with better mechanical properties [2]. Aluminium and magnesium alloys were found to be the better super plastic alloy with high specific strength. It also has lightest formational metal characteristics, so this alloy has various industrial applications [3].

The aluminium matrix alloys create the load in advance usages with light weight structures. Especially, the Al2XXX, Al8XXX, and Al6XXX possess better mechanical performances due to their resist to creep, wear, corrosion with lighter strength, high modulus strength, and enhanced temperatures [4, 5]. There is technologically necessity that is needed to increase the alloy strength. Therefore, reinforcement particle role is very crucial to improve their alloy strength. Different kinds of nanostrengthened particles were available: silicon dioxide, aluminium oxide, titanium carbide, magnesium oxide, graphite, chromium oxide, chromium carbide, etc. From these particles, boron carbide plays a fine role to improve the base alloys [6–8].

Parent material properties were much lesser than the composite-based alloy when the reinforcing was successfully blended together. Also, this reinforcement was added benefit into the mechanical properties if it supports with greatest chemical resistance, is highly potential, and reaches the maximum boiling point and light density [9, 10]. The boron carbide with various aluminium matrix composites was prepared and analyzed by the various researchers. They are clearly noted that the boron carbide strengthened particles strengthening the base alloys with enhanced hardness, compressive, tensile, and flexural properties with strongly influencing of bonding strength. Therefore, the copper-based alloys have restrict the influence of oxygen content in the composed materials due to this issue that severely affects the production section in the various engineering applications [11, 12].

Specifically, the composing of copper-based metal matrix nanocomposites produces the defect free composite specimen with ignition of oxygen and copper alloy. But these defects were not easily formed in the production of copper oxide when utilizing the blending or heating process. Sometimes, the wrongly chosen process parameters and base materials create the problems in the production of composites. Particularly, the stir casting process was not composed the proper dispersion of materials. It led to diminish the mechanical properties. So this research mainly alerted to pick the powder metallurgy process. This processing was mainly composed the better bonding interfacial strength to create the fine dispersion of reinforcement particles. Similarly, this process produces the defect free composite specimens with appropriate process parameters.

Wang et al. [13] studied the drilling parameters with nickel-based alloys by the fabrication of powder metallurgy process. Coated carbide tool performs the better machining characteristics due to the powder metallurgy-based alloy. Kishore et al. [14] studied the turning experiments on the composed metal matrix composites of 6061 and titanium carbide alloys. In this research, ANN was utilized to perform the predicted responses of surface roughness. All the values are closely related to the experimental values. Mangesh [15] presented the wire cut EDM on the 2124 with silicon carbide reinforced metal matrix composites. The artificial neural network approaches the machining responses to find out the accuracy of the predicted with experimental values. Biswajit et al. [16] developed the neural network model on the processed MMCs of copper and titanium carbide particles reinforced. Using the Taguchi L27 with ANN achieves the better predicted values. Rui-song et al. [17] developed the new material with metal matrix composites to achieve the machining characteristics. The reinforced tool achieved better mechanical responses. Ruisong et al. [18] reinforced the titanium carbide on the aluminium matrix with in situ process. The processed MMCs were approached with machinability studies. The material removal rate and surface roughness were achieved at the MMCs with required process parameters. The fine SiC creates the better machining condition with dispersion of reinforcing particles. Kumar and Chauhan [19] conducted the optimal method like ANN and response surface methodology on the processed MMCs to find the machining studies. Increasing of reinforced particles improves the mechanical attributes, and ANN was approached effectively to identify the optimal parameters and validate the parameters. From the detailed reviews, reinforcing nanoparticles is a significant influencing factor to improve the mechanical strength. Now the present study focuses the Al2024, and nanoparticles of boron carbide are selected as a material to produce the metal matrix composites by the powder metallurgy process.

Then, the processed specimens were utilized to conduct the machining performances like surface roughness and material removal rate with specified process parameters of depth of cut, speed and feed rate, respectively. The Taguchi L9 frames the design of powder metallurgy process parameters, and the artificial neural network accomplished the predicted values of machining responses. Till there is less studied was focused on the powder metallurgy composite specimen validated with ANN model. Figure 1 shows the overall research plan of this current investigation.

2. Materials and Methods

In this present research, Al 2024 as a base material which were collected as a powder material and reinforcement is nanoboron carbide particles with sizes of 20 nm. Similarly, the Al 2024 size is 100 μm. The following procedures of powder metallurgy processes are balling process, compaction, and sintering process. During the ball milling process, the selected base powders Al2024 and nanoboron carbide particles were mixed in the ball milling setup with well vibrating equipment to achieve the normalized scattering of boron carbide in the base alloy. It will take up to 1 hr for every single processing specimen. At the same time, 550 rpm of spindle speed was sustained at every 1 hr to destine the accurate mixings. Later than the ball milling process, ultrafine grain structure was achieved and that the particles were implemented to reach the next stage of compaction method. The shape is required to make the composites with suitable die sizes like 40 mm length and 25 mm dia was maintained. That the dies were needed with appropriate cavity section to compose the powder metallurgy composite specimens. While in compaction, 500 bar of pressure and 10 kN of axial loads were applied. Subsequent to compaction, sintering process was utilized to make the composite specimens by the next level. In the sintering process, compacting samples were treated with high temperature process at 1300°C with minimum 1 hr duration by the muffle furnace testing equipment. Lastly, the final composite sample was

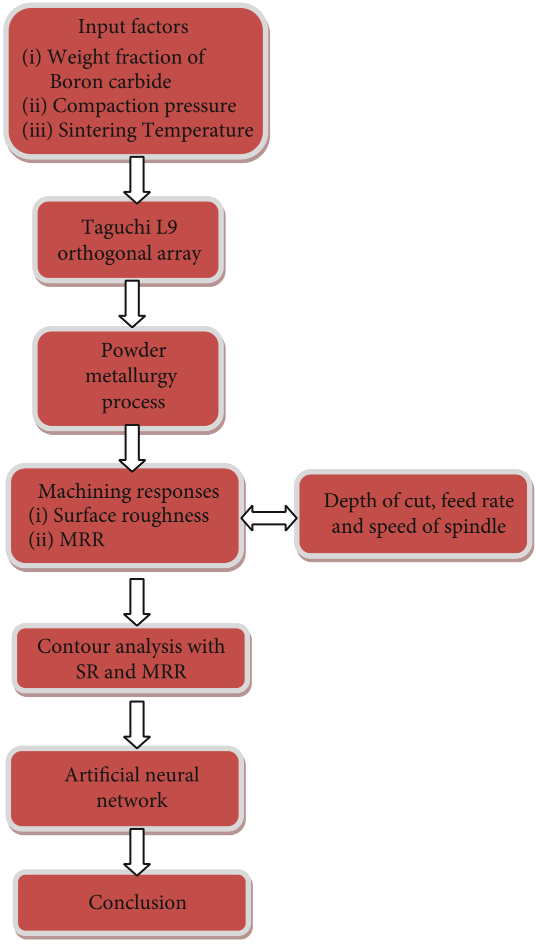

Figure 1: Overview of investigation plan.

Table 1: Processing parameters with Taguchi stages.

Processing conditions	Stage 1	Stage 2	Stage 3
Weight fraction (B_4C)	4	8	12
Compaction pressure (MPa)	300	350	400
Sintering temperature (°C)	420	480	540

Table 2: L9 array for processing parameters with L9 plan.

Sample no.	Weight fraction (B_4C)	Compaction pressure (MPa)	Sintering temperature (°C)
1	4	300	420
2	4	350	480
3	4	400	540
4	8	300	480
5	8	350	540
6	8	400	420
7	12	300	540
8	12	350	420
9	12	400	480

Table 3: Taguchi L9 with machining responses.

Sample no.	Weight fraction (B_4C)	Compaction pressure (MPa)	Sintering temperature (°C)	SR (μm)	MRR (g/min)
1	4	300	420	1.75	0.5752
2	4	350	480	1.85	0.5231
3	4	400	540	1.62	0.5925
4	8	300	480	1.48	0.6201
5	8	350	540	1.83	0.4982
6	8	400	420	1.63	0.4963
7	12	300	540	1.73	0.4596
8	12	350	420	1.68	0.5128
9	12	400	480	1.80	0.5636

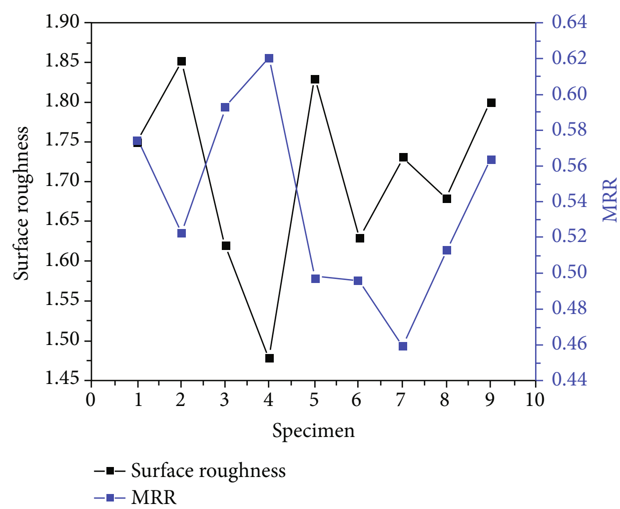

Figure 2: Machining responses with processed powder metallurgy composites.

achieved with required processing, and strongly recommended nanoboron carbide particles were highly blended with aluminium alloy 2024 [20].

The fabricated powder metallurgy composite specimens were produced with maximum strong with lighter structure without compromising to melting the supporting elements. Therefore, the above process like ball milling, compaction, and sintering was highly maintained with appropriate processing conditions during the process. The Al2024 alloy chemical compositions are 0.15 of Ti, 0.10 of Cr, 0.25 of Zn, 0.50 of Fe and Si, 1.8 of Mg, 0.9 of Mn, 4.9 of Cu, and others having 0.05 and remaining in Al, respectively. In this research, weight fraction of nanosized boron carbide was increased from 4, 8, to 12 wt. %; compaction pressure is maintained to increase the 300, 350, and 400 MPa, and the sintering temperature is 420, 480, and 540°C, respectively [21]. Therefore, the Taguchi L9 array was utilized to design the powder metallurgy process parameters with suitable values. Table 1 shows the processing parameters of powder metallurgy techniques with initial L9 array. Table 2 exhibits

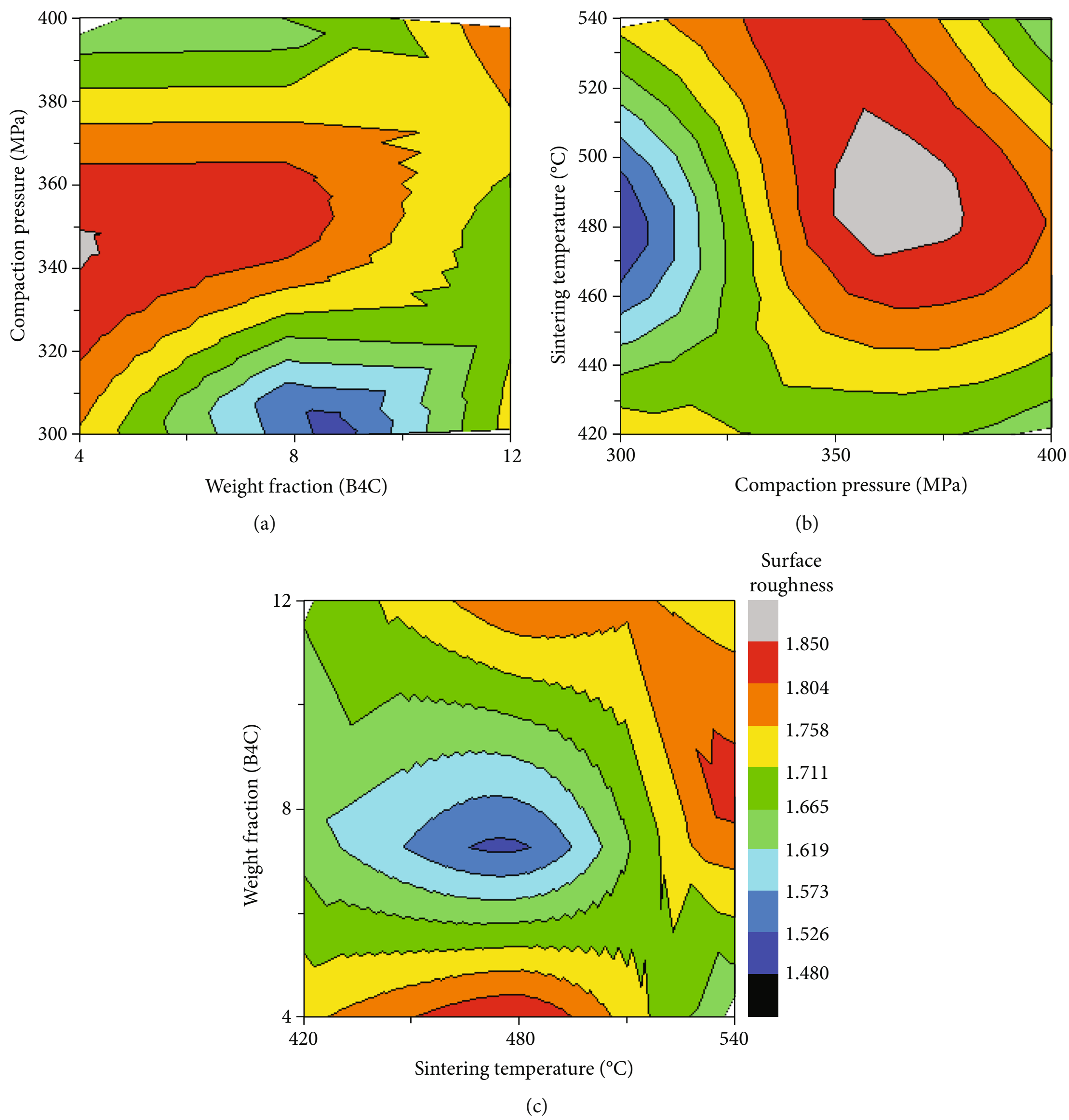

Figure 3: Surface roughness of powder metallurgy composites with (a) nanoboron carbide and compaction pressure, (b) compaction pressure and sintering temperature, and (c) sintering temperature and weight% of B_4C.

the overall processing parameters of powder metallurgy with L9 array of Taguchi technique [22].

3. Results and Discussions

As per the Taguchi L9 design, all the process parameters of powder metallurgy process were arranged. In the L9 methods, overall nine samples were prepared from the processed powder metallurgy composites with respective parameters of weight fraction of boron carbide, compaction pressure, and sintering temperature, respectively [23]. From the detailed analysis of process parameters, processed composite specimens were desired to achieve the machining process [24]. The conventional turning process was accomplished in the entire nine composite specimens. During this machining, process-maintained parameters were fixed to improve their specimen's character [25]. The machining parameters such as spindle speed (220 rpm), cutting speed (45 m/min), feed (0.120 mm/rev), and depth of cut (0.50) show optimum condition [26].

The machining experiments were conducted on the multigeared lathe machine with respective of maintained parameters. Mitutoyo equipment was utilized to carry out the surface roughness with automated portable roughness tester. The measuring tip was maintained with 0.80 mN and 0.30 mm/speed. The conical taper angle was fixed at 90°. Similarly, the material removal rate was measured with combination of depth of cut, times measuring of width of cut, and feed rate, respectively. Table 3 displays the powder metallurgy composite specimen with L9 for machining responses of surface roughness and processed composite material removal rate [27]. From Table 3, the surface roughness and material removal rate were attained with various process parameters of powder metallurgy techniques. It is understood that the

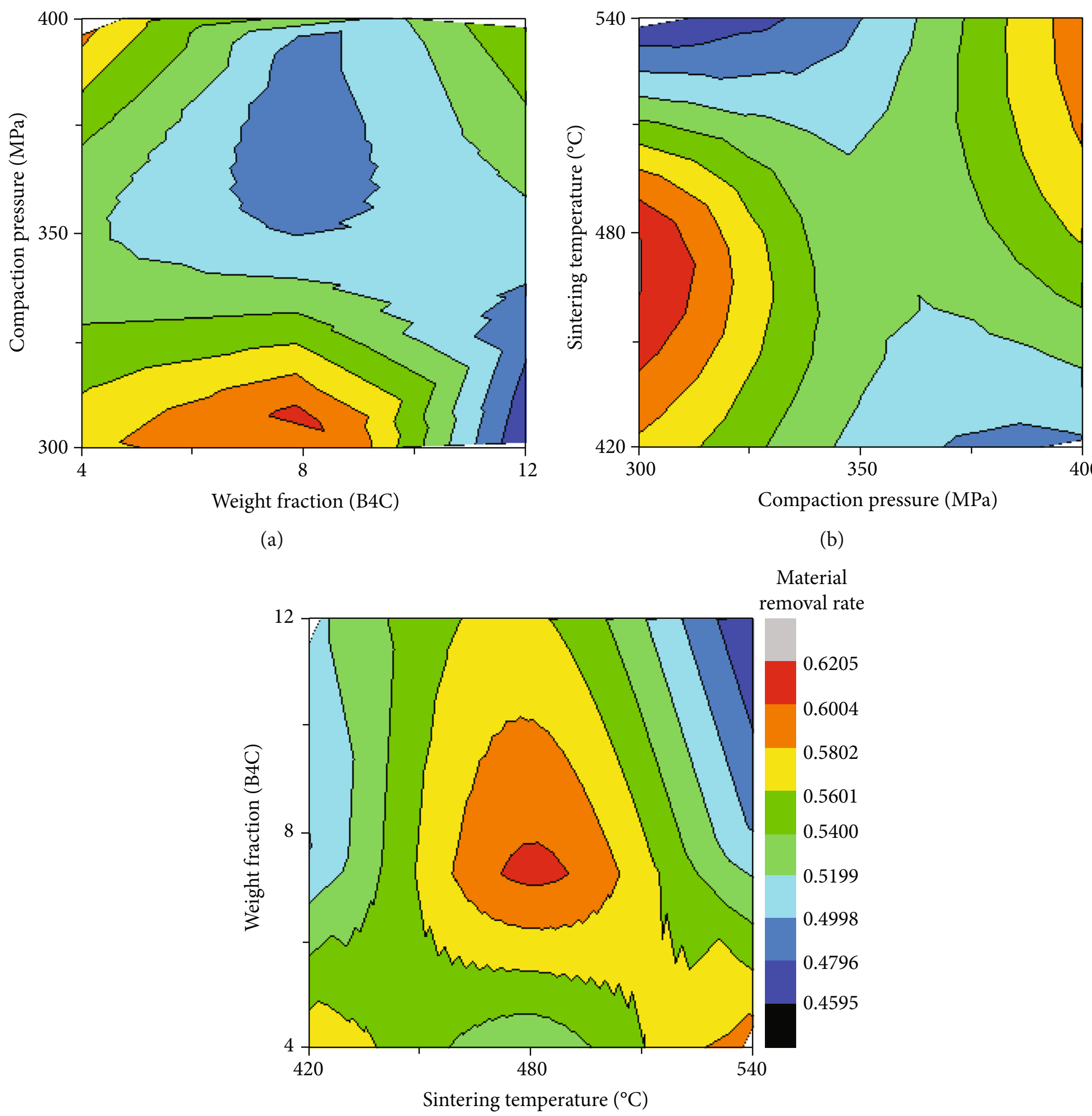

FIGURE 4: Material removal rates of powder metallurgy composites with (a) nanoboron carbide and compaction pressure, (b) compaction pressure and sintering temperature, and (c) sintering temperature and weight% of B_4C.

TABLE 4: Predicted ANN values of machining responses.

Sample no.	Weight fraction (B_4C)	Compaction pressure (MPa)	Sintering temperature (°C)	SR (μm)	Predicted ANN for SR	MRR (g/min)	Predicted ANN for MRR
1	4	300	420	1.75	1.812	0.5752	0.6215
2	4	350	480	1.85	1.901	0.5231	0.5891
3	4	400	540	1.62	1.689	0.5925	0.6102
4	8	300	480	1.48	1.525	0.6201	0.6354
5	8	350	540	1.83	1.789	0.4982	0.5326
6	8	400	420	1.63	1.692	0.4963	0.5001
7	12	300	540	1.73	1.725	0.4596	0.4824
8	12	350	420	1.68	1.710	0.5128	0.5650
9	12	400	480	1.80	1.882	0.5636	0.5821

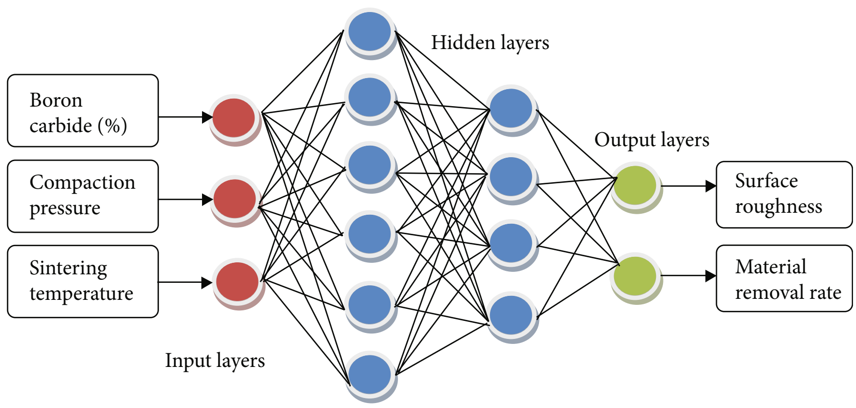

Figure 5: Neural network models with arranged layers.

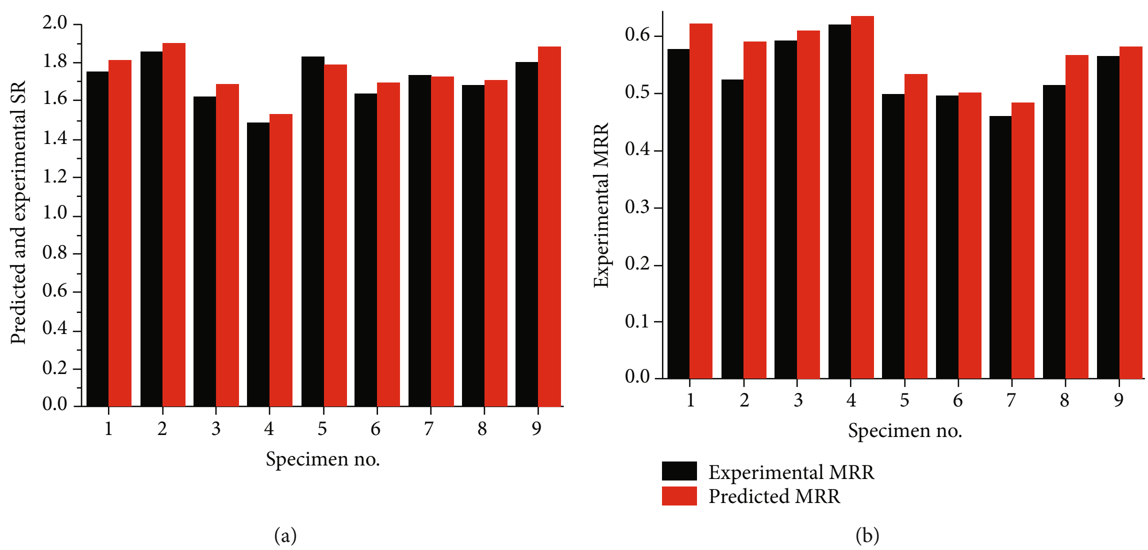

Figure 6: (a) Experimental and predicted values of surface roughness. (b) Experimental and predicted values of material removal rate.

minimum surface roughness and maximum material removal rate were greatly attained at specimen 4.

The specimen parameters are 8% wt. of nanoboron carbide, 300 MPa of compaction pressure, and 480°C of sintering temperature. The weight percentage of boron carbide with moderate level 8% was the major reason to achieve the better machining responses. At the same time, low level compaction pressure and high level sintering temperature achieve the fine responses [28]. Figure 2 exhibits the interactions of surface roughness and material removal rate on the 9 processed composite specimens.

3.1. Contour Plot Analysis of Machining Responses. Figures 3(a)–3(c) show the machining responses of processed powder metallurgy composites with process parameters. Figure 3(a) exhibits the weight fraction of B_4C and compaction pressure on the processed composites. From Figure 3(a), it is understood that the surface roughness was improved with increasing of boron carbide at 8 to 12 wt. percentage and with low level of compaction pressure 300 MPa, respectively. Therefore, increasing boron carbide improves the machining responses with homogeneous presence of boron on the aluminium 2024 alloy. Figure 3(b) shows the combinational effect of sintering temperature and weight fraction of boron carbide on the surface roughness responses. From Figure 3(b), surface roughness was improved at the low level compaction pressure and medium level of sintering temperature [29]. Therefore, the moderate temperature achieves the better composite fabrication with sufficient machining temperatures which easily withstand in the processed composites. Figure 3(c) shows the sintering temperature and weight fraction of boron carbide with surface roughness. From Figure 3(c), it is revealed that the optimal surface roughness was highly attained at the medium level of sintering temperature and weight fraction at 8% B_4C [30]. Therefore, this surface roughness was highly accumulated in the medium level weight fraction at 8% of boron carbide, low level of compaction pressure 300 MPa, and medium level of temperature 480°C.

Figures 4(a)–4(c) show the machining responses of processed powder metallurgy composites with process parameters. Figure 4(a) exhibits the weight fraction of B_4C and compaction pressure on the processed composites for material removal rate. From Figure 4(a), it is understood that the material removal rate was enhanced with increasing of boron carbide at 8 to 12 wt. percentage and with low level of compaction pressure 300 MPa, respectively. Therefore increasing boron carbide improves the machining responses with homogeneous presence of boron on the aluminium 2024 alloy. The interfacial bonding was highly accumulated in the processed composites with this parameter. Figure 4(b) shows the combinational effect of sintering temperature and weight fraction of boron carbide on the material removal rate. From Figure 4(b), material removal rate was highly responded at the low level compaction pressure (400 MPa) and medium level of sintering temperature 480. Therefore, the moderate temperature achieves the better composite fabrication with sufficient machining temperatures which easily withstand in the processed composites. Figure 4(c) shows the sintering temperature and weight fraction of boron carbide with material removal rate. From Figure 4(c), it is revealed that the maximum material removal rate was highly attained at the medium level of sintering temperature and weight fraction at 8% B_4C. Therefore, this material removal rate was highly accumulated in the medium level weight fraction at 8% of boron carbide, low level of compaction pressure 300 MPa, and medium level of temperature 480°C.

3.2. ANN of Predicted Surface Roughness and Material Removal Rate. In this research, artificial neural network technique was implemented to identify the predicted outcomes of surface roughness and material removal rate. This method was highly achieved with predicted values, and it was very useful to improve the machining responses by the next level. Levenberg–Marquardt technique was used to implement the predicted outcomes. The feed forward and back propagation algorithm was used to analyze the trial and error methods. This trial error methods hidden layers, input layers, and output layers are approached with the input process parameters and output responses. From the prior arrangements of L9 array with outcomes, table was fetched with the ANN predicted values. The input layers have a structure like 3, 6 and 4 hidden data structures. Finally, the two output factors have two structures. Table 4 exhibits the predicted experimental outcomes with ANN. From Table 4, it is revealed that the most experimental values are getting maximum predicted values. Therefore, this ANN model was further utilized to implement modeling approaches on the process parameters. Figure 5 shows the arranged ANN structure for input, hidden, and output layers. Similarly, Figures 6(a) and 6(b) exhibit the predicted values and experimental values of surface roughness and material removal rate, respectively.

4. Conclusions

This research conducts the powder metallurgy process on Al2024 and B_4C successfully.

The process parameters like sintering temperature, compaction pressure, and weight percentage of B_4C achieve the better interfacial bonding when analyzing the turning studies.

The Taguchi L9 array was completely designed the parameters and to understand easily with their machined responses surface roughness and material removal rate.

As per the constant parameters of turning like depth of cut, feed, and speed compose the better machining.

The maximum material removal rate was highly attained at the medium level of sintering temperature and weight fraction at 8% B_4C.

Therefore, this material removal rate was highly accumulated in the medium level weight fraction at 8% of boron carbide, low level of compaction pressure 300 MPa, and medium level of temperature 480°C.

Data Availability

The data used to support the findings of this study are included within the article. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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