Hindawi
Journal of Nanomaterials
Volume 2022, Article ID 3577793, 9 pages
https://doi.org/10.1155/2022/3577793

Research Article

Optimization on Powder Metallurgy Process Parameters on Nano Boron Carbide and Micron Titanium Carbide Particles Reinforced AA 4015 Composites by Taguchi Technique

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Received 16 February 2022; Accepted 11 May 2022; Published 15 June 2022

Academic Editor: Palanivel Velmurugan

Aluminium metal matrix composite is developed using powder metallurgy, with number of different operational factors considered. The three most important operational factors are sintering time, sintering temperature, and compaction pressure. Investigations are conducted using L9 orthogonal array as the experimental design. Density, Vickers hardness, and compressive strength are determined through experiments. The S/N ratio based on Taguchi's law and a number of anomalies accomplished were used to determine the effect of individual input parameters (ANOVA). The main effect plots identified the optimal parameter settings for obtaining a less density, a higher hardness, and a higher compressive strength. In addition, the ANOVA analysis confirmed that the best metal matrix composite material is produced at the optimal sintering time and average temperature and compaction pressure for generally classified levels.

1. Introduction

There has been an increase in composite research, and the results have produced some truly remarkable solutions to many difficult problems. Despite this, the requirement for an alternative strength and stability material remains constant [1]. Selecting composite materials and developing composite materials are still difficult and time-consuming tasks. Composite materials made from metal and polymer, such as MMC and PMC, find use in numerous engineering fields [2, 3]. In structural applications, the AMMC is a great engineering material. Aluminium-based composites are preferred over

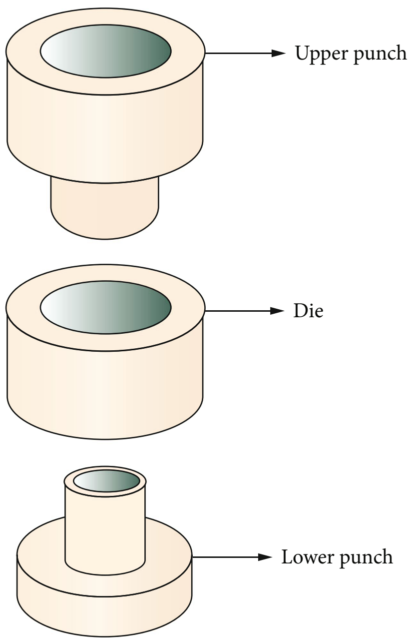


Figure 1: Structure of punches and dies.

Table 1: Process parameters for compacting Al+micron TiC+nano B4C powder.

Parameter for the process	Range	Units
Sintering time	2, 2.25, 2.5	hr
Sintering temperature	620, 640, 660	°C
Compacting pressure	300, 350,400	MPa

traditional metals due to their high strength, low weight, and excellent deformation characteristics [4–6]. Complex geometry is simple to fabricate. Components out of aluminium-based composites have good thermal and electrical conductivity as well as being soft and affordable [7]. These metal matrix composites are highly resistant to chemical/electrochemical corrosion and vibration damping [8]. Added fillers and reinforcements have improved the metallurgical and the composite's mechanical properties. Composites with a metal matrix are made using a variety of processes, all of which contribute to the final product's enhanced properties [9–12]. AMMC materials are frequently developed using the powder compaction method. The use of rough particles and an aluminium matrix is extensively documented in the scientific literature [13].

A variety of aluminium matrix and reinforcing material combinations have been extensively studied and are now flooding the market for a variety of applications [14–17]. Although researchers have experimented with a variety of new reinforcements, the inherent properties of B4C and TiC have drawn their attention. Among the uses for B4C-reinforced Al composites are armored vehicles, bulletproof clothing, and aircraft components like the joints. Engine cylinder, piston, and engine frame liners all use TiC-reinforced Al composites, which have excellent thermal stability and damping strength [18]. B4C and TiC's impressive properties include very low density, higher in strength, upright wear resistance, and chemical solidity, in addition to their high hardness [19–22]. Increases in the weight of hard particle reinforcement lead to decreases in the underlying mechanical properties. When it comes to mechanical properties, Al matrix materials with 20% SiC reinforcement were studied by [23]. This can lead to catastrophic mechanical failure in unexpected applications due to the heterogeneous metal-silicon structure in Al-SiC composites with an extreme SiC weight % [24]. It has been discovered that as the reinforcement weight percentage (in increasing mode) changes, the hardness and ductility of the material change as well [25]. It is possible to obtain the desired properties and metallurgical quality using only Al MMCs reinforced with B4C and the appropriate processing conditions [26–28]. To create hybrid composites, two or more different reinforcing materials with varying properties are mixed into the matrix material; these hybrid composites have an advantage over traditional composites due to their increased strength [29]. Sample research has been accomplished in the development of MMC material, as evidenced by the literature reviewed. The main focus of the current research is on different reinforcement combinations and evaluation of mechanical properties [30].

This study uses different weight ratios of AA4015, micron TiC, and nano B4C and processes MMCs under a variety of conditions. As an outcome, the finished composites' mechanical properties were evaluated [31].

2. Experimental Methodology

2.1. Handling and Preparation of Composite Materials. This project's AA4015 aluminium framework was fortified with micron TiC and nano B4C for increased sturdiness. For processing, material with a diameter of 300-330 μm was obtained. Standard suppliers, likewise, offer 30 μm TiC particle and 40 nm B4C as options. Aluminium AA4015, TiC, and B4C metal powders have 96% aluminium AA4015, 3% micron titanium carbide, and 1% nano boron carbide, respectively. This process uses a ball mill for 15 minutes to incorporate metal powder proportions that remain constant throughout at a speed of 300 rpm to ensure an even blend. Following the arrangement of the punches and dies, the powder compaction process is performed. Steel is used for the die steel materials that make up the compaction die and punch. The ejected specimens are cylindrical in shape and measure about $\phi 20 \times 15$ mm in size. Using a camera, we were able to capture a photo of AA4015+micron TiC+nano B4C powder being compacted green. The amount of metal powder needed for single-sample compaction is 40 g. Consequently, all specimens for comparison and investigation will maintain the same uniformity. Heavy hydraulic presses of 10 tonnes each compact metal powder and the schematic is shown in Figure 1. The specimen-making compaction force used in this study is measured in MPa and varies between 300 and 400 MPa. Table 1 shows the degree of variation in each of these variables.

Table 2: Composite development based on a plausible combination of process criterion.

Exp no.	1	2	3	4	5	6	7	8	9
Sintering time (hour)	2	2	2	2.25	2.25	2.25	2.5	2.5	2.5
Sintering temperature (°C)	620	640	660	620	640	660	620	640	660
Compaction pressure (MPa)	300	350	400	350	400	300	400	300	350

Table 3: Al AA4015+TiC+B4C extracted composite density and S/N ratio values.

Exp no.	1	2	3	4	5	6	7	8	9
Sintering time (hr)	2	2	2	2.25	2.25	2.25	2.5	2.5	2.5
Sintering temp (°C)	620	640	660	620	640	660	620	640	660
Compaction pressure (MPa)	300	350	400	350	400	300	400	300	350
Density (g/cc)	2.93	3.18	3.12	2.76	3.05	2.86	3.16	2.78	3.22
S/N ratio	-8.2498	-8.0685	-9.0182	-9.2876	-9.7456	-9.0812	-8.0218	-9.0124	-8.9876

Table 4: ANOVA results for density.

Source	Sintering time (hr)	Sintering temperature (°C)	Compaction pressure (MPa)	Error	Total
DF	2	2	2	2	8
Seq SS	0.005589	0.026756	0.097956	0.044822	0.226422
Adj SS	0.009105	0.028956	0.088967	0.035722	—
Adj MS	0.004154	0.011178	0.047599	0.023921	—
F	0.442	0.6821	4.90211	—	—
P	0.945	0.6011	0.3252	—	—

2.2. Taguchi Method. The Taguchi technique optimizes process parameters while lowering the number of tests necessary based on S/N ratio. The primary goal of this paper is to find the optimum process parameters for the development of high hardness and compressive strength in combination with a low-density strength composite. As a result, for density, the smaller the quality characteristics the better for High hardness and compressive strength in combination with a low density, the better. ANOVA was used to examine the effect of each process parameter on material qualities. ANOVA may also be used to figure out how an experimental set of data is affected by a particular set of operating factors. The most likely sample collection combinations of input are shown in Table 2.

2.3. The Evaluation and Testing of Composites. A procedure for green compaction to make the samples was carried out, and then a specific temperature and time were used to sinter them. For quality assessment, a minimum of 4 test specimens of each combined application were prepared. After sintering and curing, samples are put through a series of mechanical tests. To evaluate the specimen's mechanical properties, researchers look at its density, microhardness, and compression strength. Based on the Archimedes principle, densities have been calculated with a density meter. A 100 g applied weight was applied to the samples, and their rigidity was measured using metallurgically polished surfaces. The compression strength of a new sample is tested by loading it into a universal loading machine. To find the best process parameter, the data is tallied and mathematically analyzed. For each sample, conclusions are drawn based on the process parameters that were provided as input. The best process parameter combination was discovered and reported as a result of the discussion.

3. Results and Discussion

To create aluminium AA4015 wt. 96% metal matrix, researchers used titanium carbide and boron carbide reinforcement particles (3% TiC+1% B4C). The process parameters used to create the composite were varied.

3.1. Density of Sintered (Aluminium AA4015+Micron Titanium Carbide+Nano B_4C) Composites. Specimens made according to the sintering time, compaction pressure, and sintering process specified in the run order were studied for Al AA4015+TiC+B4C composite density, hardness, and compressive strength. In each case, a minimum of three samples were examined. This sintered aluminium AA4015 +titanium carbide+boron carbide composite's density is critical. In accordance with ASTM standards, the developed composite's density is shown in Table 3. Pure aluminium powder has a density of 2.7 g/cc. When the composite was processed under various conditions, it yielded an average density ranging from 2.58 to 2.91 g/cc. Amount of compaction used a large impact on density. In other words, the

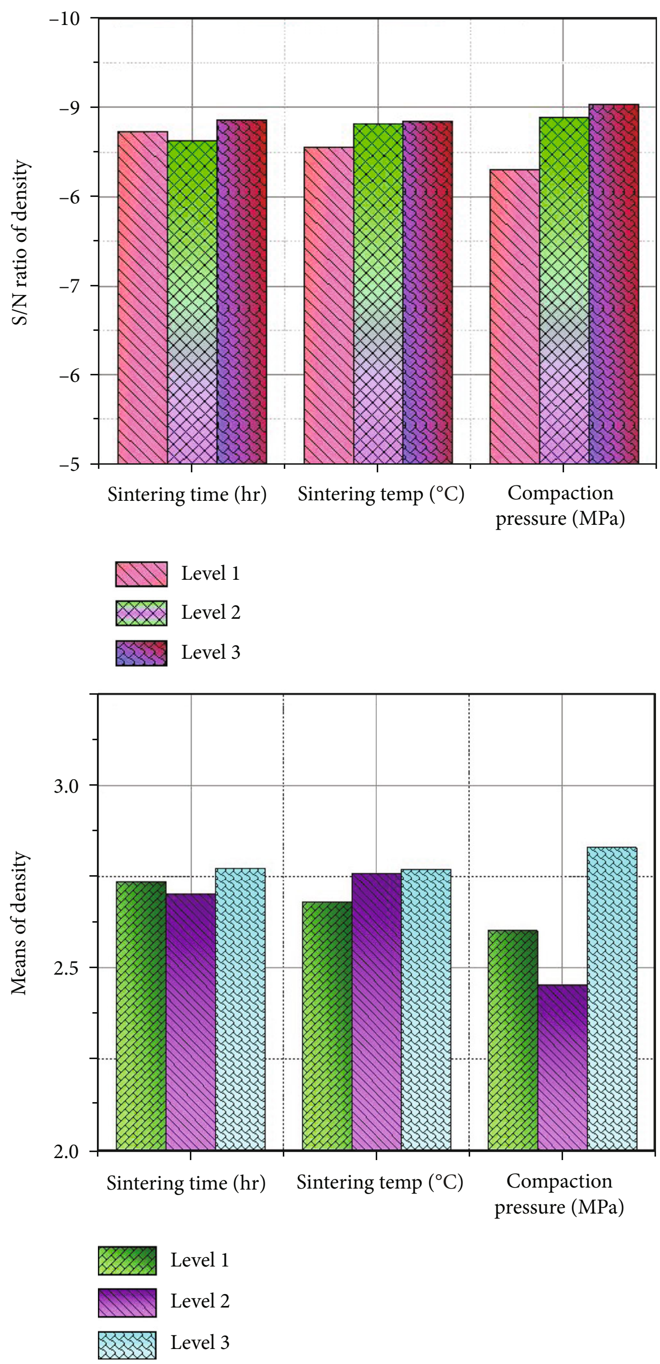


Figure 2: Density response graph.

maximum average density for a 350 MPa compaction load sintered at 660°C for 2.5 hours is 3.29 g/cm^3. When sintered at 620°C for two hours with a 300 MPa compaction load, the average density is 2.58 g/cc. All parameters' values differ maximally in both scenarios. ANOVA and the S/N ratio are used to analyze experimental data to draw conclusions about process parameter and it is shown in Table 4.

The sound to noise ratio and density mean response figure are shown in Figure 2. The metal alloys will versatile within the specified volume during contraction due to the high compaction load used in this study. The powder particle begins to fuse and approaches metallurgical bonding through the heating and quenching of the green compact. This means that the sintering temperature plays an important role in determining how long it takes for the material to sinter. Low density was achieved by sintering for two hours at 620°C with a compaction pressure as high as 250 MPa. In addition, compaction pressure, which accounts for 66.58 percent of the total and sintering temperature, which accounts for 12.82 percent, is confirmed as the most important parameter, and the values are shown in Figure 3.

3.2. Microhardness of Sintered (Aluminium AA4015+Micron Titanium Carbide+Nano Boron Carbide) Composite. Before

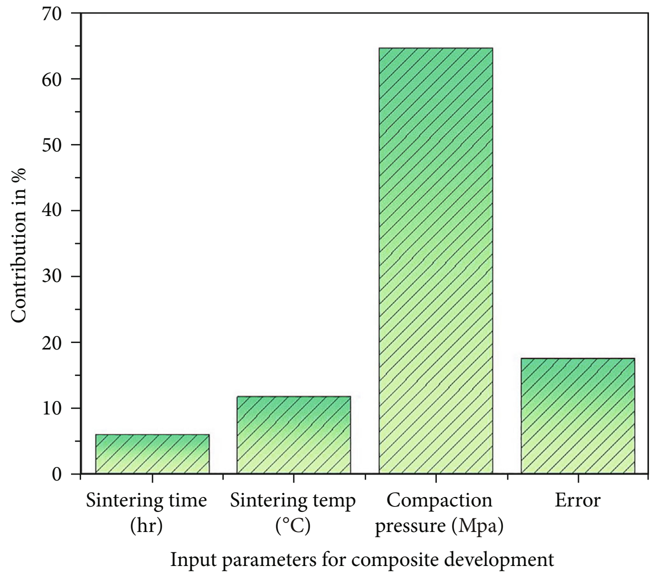


FIGURE 3: Input parameter effect on composite density of AA4015, titanium, and boron carbides.

TABLE 5: AA4015+TiC+B4C processed composite hardness and S/N ratio value.

Exp no.	1	2	3	4	5	6	7	8
Sintering time (hr)	1.75	1.75	1.75	2	2	2	2.25	2.25
Sintering temperature (°C)	610	620	635	610	620	635	610	620
Compaction pressure (MPa)	250	300	350	300	350	250	350	250
Hardness (Hv)	26	28.82	29.62	28.79	29.18	25.82	30.22	27.64
S/N ratio (dB)	29.525	29.802	30.226	30.22	31.23	29.65	31.42	29.22

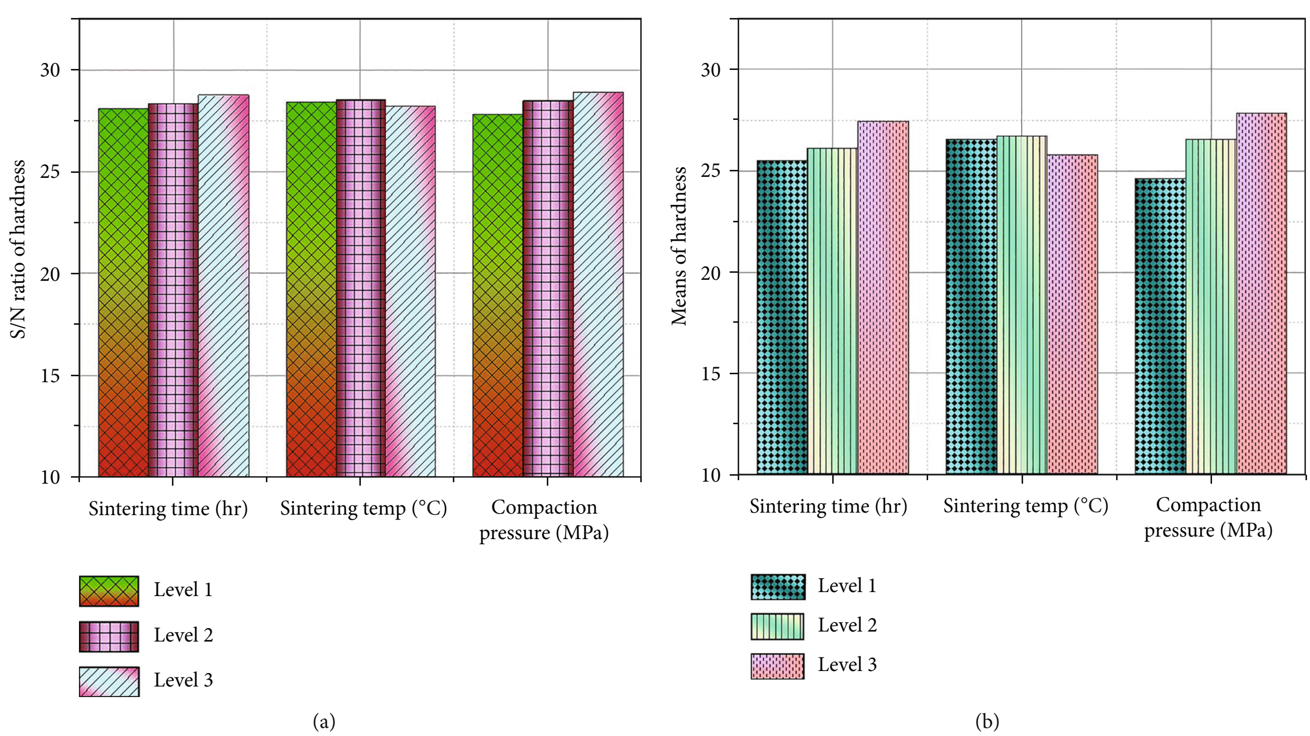


FIGURE 4: Graph for response of hardness.

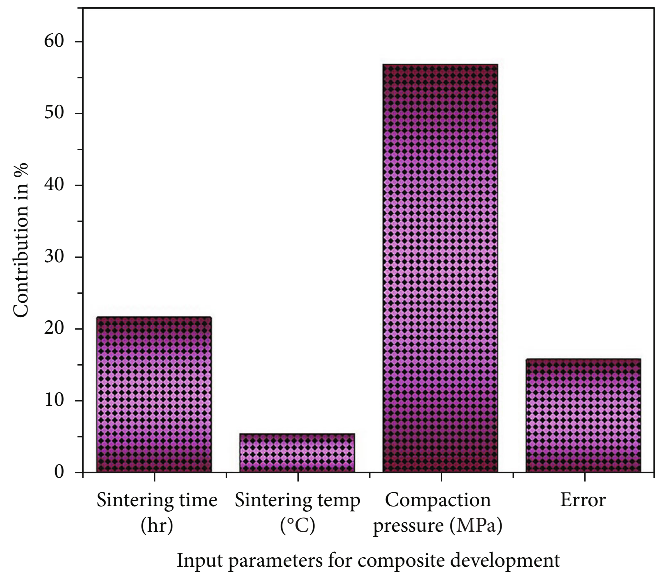


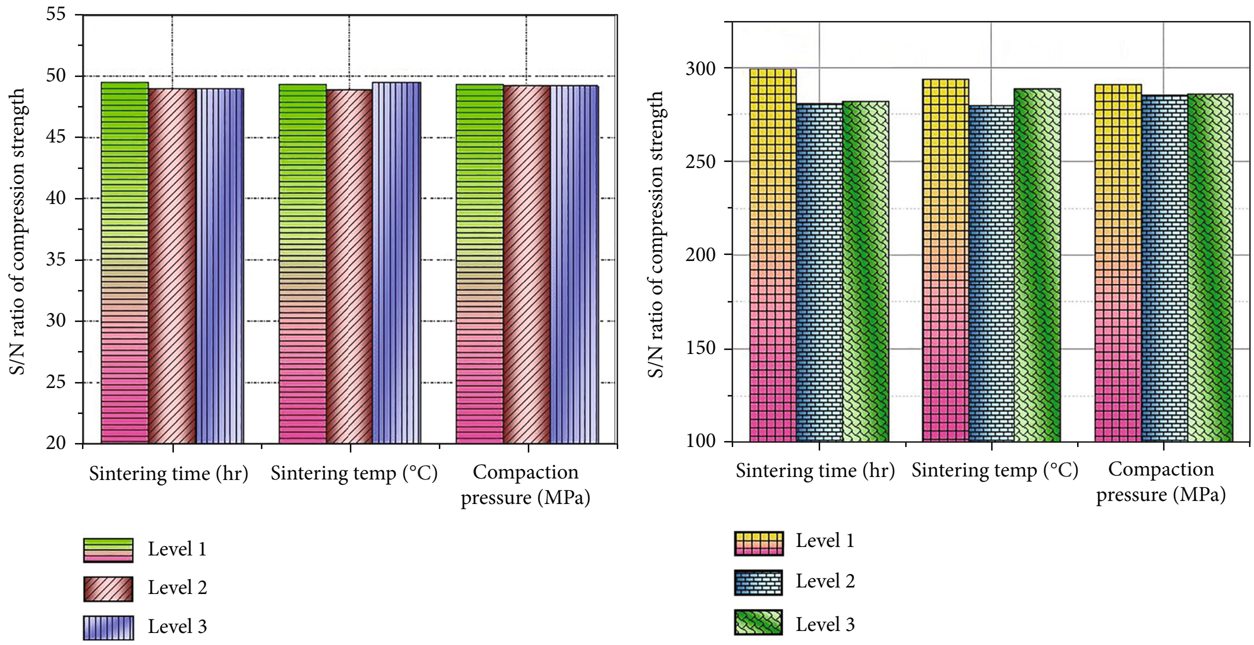
Figure 5: The effect of parameters on the hardness of a composite of AA4015+titanium carbide+boron carbide.

Table 6: ANOVA results for hardness.

Source	Sintering time	Sintering temp	Compacting pressure (MPa)	Error	Total
DF	2	2	2	2	8
Seq SS	6.185	1.526	16.21	4.426	28.6
Adj SS	5.901	1.621	16.136	4.581	—
Adj MS	2.981	0.786	8.12	2.289	—
F value	1.426	0.312	3.61	—	—
P value	0.399	0.762	0.225	—	—

the diamond indentation test, the samples are mechanically smoothed and ethanol was used to clean the area, which determines the sample's micro-Vickers hardness. This is done after the density measurement has been completed. Using the ASTM standard procedure, we randomly selected three spots from each sample. Sample 1's average hardness value is 1, and samples 2 and 3's hardness values are 2 and 3, respectively. Determined using a similar procedure for samples 2 and 3. Table 5 shows that the average measured hardness value ranges from 22.26 Hv to 30.26 Hv. The hardness of aluminium AA4015 powder is 26 Hv on the Mohs scale. Metallurgically, the results show that heat treatment increases surface hardness when powder is compacted with high density and low permeability. At a compaction pressure of 300 MPa, the average hardness found in experimental trial 1 was 23 Hv. After 2.5 hours of compression and sintering at 660°C, the same powder had a 29.78 Hv which is the highest possible level of surface hardness. Table 5 also includes data on the hardness S/N ratio and mean response. The compaction pressure and sintering time have a direct relationship with compound hardness, as shown in the table. The sound to noise ratio and density mean response figure are shown in Figure 4. Figure 5 shows the main effect plot, which shows how input process parameters affect hardness. 640°C and 400 MPa compaction pressure were used for 2.5 hours of sintering to achieve the high hardness. To find out how process parameters affected hardness, researchers used an ANOVA as in Table 6. Compaction pressure accounts for 56.78% of the total, with sintering time accounting for 23.82 percent of the total. Significantly, the bulk material properties of a material are improved when the density is high and there are few pores/voids. Surface hardness during subsequent heat treatment depends on how long it takes to heat the powder to a fusion temperature for use in metallurgical bonding.

3.3. Compression Strength of Aluminium AA4015+Micron Titanium Carbide+Nano Boron Carbide Metal Matrix Composite. Compression testing was carried out on the Al AA4015+TiC+nano B4C specimens to find out how strong they were when loaded from the bottom. The experimental trial 1 sample can withstand up to two hours of processing at 300 MPa compression pressure and 620°C sintering temperature with a maximum load of 58.68 kN and ultimate strength of 390.62 MPa compression strength as shown in Figure 6. A ductile failure is caused by agitating the material. Instead of an oval, the compressed sample looks like a circle with brittle or buckled ends. Because the compressed sample's surface is well-finished, a high friction coefficient is obtained for a uniform distribution of the material during compression. As a result of microcracks, the edges fail and open due to surface tensile loading. Table 7 summarizes the Al AA4015+TiC+B4C composite material's compression strength. The S/N ratio was calculated and reported based on the experimental results for the proposed investigation of the process parameter. S/N ratio and compression strength response mean tables are shown in Table 8. Studies have found the most impact on final product quality is sintering time, followed closely by sintering temperature and compaction pressure. According to the findings of the researchers,



(a) (b)

Figure 6: Response graphs for compressive strength.

Table 7: Compression strength and sound to noise ratio value of Al AA4015+TiC+B_4C sorted materials.

Exp no.	1	2	3	4	5	6	7	8	9
Sintering time (hr)	2	2	2	2.25	2.25	2.25	2.5	2.5	2.5
Sintering temp (°C)	620	640	660	620	640	660	620	640	660
Compaction pressure (MPa)	300	350	400	350	400	300	400	300	350
Compression pressure (MPa)	329.36	300.06	314.16	300.11	291.47	296.19	297.26	292.55	301.5
S/N ratio (dB)	52.518	51.667	52.087	51.668	51.401	51.548	51.581	51.435	51.711

Table 8: ANOVA results for compression strength.

Source	Sintering time (Hr)	Sintering temp (°C)	Compacting pressure (MPa)	Error	Total
DF	2	2	2	2	8
Seq SS	658.08	317.2	58.7	142.6	1176.58
Adj SS	665	318.4	59.4	143.78	—
Adj MS	331.6	162.7	28.3	70.32	—
F-value	5.72	2.34	0.521	—	—
P-value	0.21	0.29	0.76	—	—

increasing the sintering time and ensuring that metallic powders are appropriately diffused to form a metallurgical bond can both improve the material's strength.

On main graph for compression as shown in Figure 6 are PM process parameters and their influence on the compressive strength. 620°C and 300 MPa compaction pressure were used for a two-hour sintering period to achieve the maximum compression strength. Table 8 and Figure 7 summarize the ANOVA results and the effect of each parameter on compression strength. Sintering time (52.76%) and temperature had an impact on compression strength (27.62%).

3.4. Combined Density, Hardness, and Compression Strength Effects of the Various Parameters. In order to demonstrate the combined effect of process parameters on response, an interaction plot can be used. The presence of nonparallel lines indicates the presence of the interaction effect and vice versa. Higher values of hardness are observed at increased compaction pressure values. High compaction pressure increases hardness by reducing porosity and perfectly packing reinforcements between the matrix. Temperature and compaction pressure have a strong relationship at low temperatures, but not at high ones. Sintering temperature and compaction pressure. A longer sintering time has a significant interaction effect with compaction pressure; however, a shorter sintering time has no significant interaction.

3.5. Optimized Parameters. The optimal set of process parameters for achieving compressive strength despite its low density and high hardness in an Al AA4015+micron TiC+nano B4C composite material is shown in Table 9.

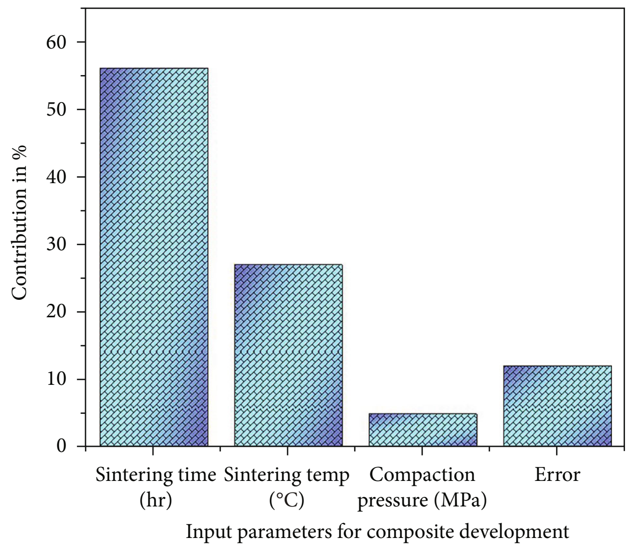


FIGURE 7: Constrained input parameters on compression strength of AA4015+TiC+B_4C composite.

TABLE 9: Optimized parameters.

Output response	Optimum parameter level Sintering time (Hr)	Sintering temp (°C)	Compacting pressure (MPa)
Density (g/cc)	2.25	640	300
Hardness (Hv)	2.5	640	400
Compression strength (MPa)	2	620	300

4. Conclusions

The PM route was used to add micron TiC and nano B4C reinforcement to an AA4015 matrix to create the composite material. The Taguchi method was used to assess each input parameter individually. The following are the study's conclusion:

(1) For achieving low density in composites, the best parameters were found to be 2.25 hr sintering time, sintering temperature of 640°C, and compaction pressure of 300 MPa. Among the parameters tested, compaction pressure had the greatest impact, accounting for 75.68 percent of the total effect

(2) For achieving high hardness, the sintering time is 2.5 hours, the sintering temperature is 640°C, and the compaction pressure is 400 MPa. Compaction pressure is the most important factor affecting hardness, followed by sintering time

(3) The greatest possible compressive force can be achieved by using a two-hour sintering time, a 620°C sintering temperature, and a 300 MPa compaction pressure. Compression strength is primarily affected by sintering time and sintering temperature

Data Availability

The datas used to support the findings of this study are included within the article. Further data or information is 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.

Acknowledgments

The authors appreciate the supports from Mizan-Tepi University, Ethiopia, for the research and preparation of the manuscript. This study was supported by the Princess Nourah Bint Abdulrahman University, Riyadh, Saudi Arabia (Researchers Supporting Project Number PNURSP2022R71).

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