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Research Article

Evaluation on Powder Metallurgy Process Parameters of Ball-Milled AA8079-B_4C Nanostructured Composites via Taguchi Grey Relational Analysis

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This work made an attempt to optimize the powder metallurgy (PM) process parameters of ball-milled AA8079-B_4C composites via Taguchi grey relational analysis to attain better mechanical properties. The process parameters are reinforcement weight percentage, compaction pressure, sintering temperature, and sintering time, and the output responses are micro Vickers hardness and compressive strength. The different reinforcement weight percentages are AA8079-x wt.%B_4C ($X = 5$, 10, and 15 wt.%). The nanograin-refined green compacts were made at various compaction pressure 200 MPa, 300 MPa, and 400 MPa. The various sintering temperatures are 375°C, 475°C, and 575°C at different sintering times 1 h, 2 h, and 3 h. Taguchi L_{27} orthogonal array was utilized to examine the powder metallurgy process parameters. It could be understood from the results that higher reinforcement weight percentage, compaction pressure, and sintering temperature were determined as appropriate parameters to obtain maximum hardness and compressive strength.

1. Introduction

Metal matrix composite (MMC) offers a symbiotic blend of properties; this could not be obtained in traditional materials. The MMCs can be attained by combining particulates B_4C, SiC, Al_2O_3, AlN, and Ash into less weight alloys are the preferred to substitute traditional materials in numerous usages defence, structural, automobile, aerospace, marine, and mining industries [1–3]. Owing to the less density, better specific strength and better thermal conductivity aluminium alloys are extensively utilized [4]. To fulfill the necessities such as better mechanical properties and wear resistance of aluminium matrix composites (AMCs), AMCs are reinforced with outstanding structural, and physical properties are significantly required [5, 6]. Amid the different reinforcements, boron carbide (B_4C)

possesses extreme hardness subsequent to diamond and cubic boron nitride. Moreover, B_4C has lesser specific gravity (2.51 g/cm^3), and this is lower than Al (2.7 g/cm^3). B_4C possesses extreme wear and impact resistance, better resistance to chemical agents, and high melting point [7, 8]. Despite of extreme mechanical properties, the utilization of B_4C reinforcement has been improved extremely [9, 10].

Powder metallurgy (PM) production method includes various steps, namely, blending of powders, compaction, sintering, and secondary finishing method to manufacture parts with reliable net-shape. Metal components produced through PM can be utilized in automobile, aerospace, defence, and electronic industry because of its superior physical and mechanical properties. Near net shape components can be fabricated via PM method; furthermore, material wastage can be eliminated. Uniform distribution of reinforcement particle with matrix can be attained [11, 12]. Precision metal components can be fabricated through PM route so this technique has been acknowledged as extremely established technique. In the course of the most recent seven eras, the innovation has developed from fabricating bearings for autos to difficult transferor gear set in vehicle transposal and engines connecting rods [13]. Figure 1 shows the process sequence for fabrication of MMC using PM. Nowadays, many of the researchers focused to study the powder metallurgy process parameters such as reinforcement weight percentage, compaction pressure, and sinterability [14–18]. Zakir Hussain et al. [19] examined the powder metallurgy process parameters of diamond–copper composites in terms of compaction pressure, sintering temperature, and holding time and reported that compaction pressure 525 MPa, sintering temperature 900°C, and holding time 2 h are the most influencing parameters. Pravin et al. [20] utilized Taguchi system to optimize the process parameters of Al-10% Cu composites, and the process parameters are compaction load, lubricant, sintering atmosphere, and dwell time and stated that lubricant is a major influencing parameter. Ravichandran and Anandakrishnan [21] examined the PM parameters to obtain higher strength coefficient in aluminium matrix composite via Taguchi method and described that compaction pressure and sintering temperature are major substantial parameters.

From the detailed literature study, it has been clearly evidenced that many of the researchers investigated the powder metallurgy process parameters as in Figure 1 using different matrix materials and reinforcement particles but none of the work has been carried out in AA8079-B_4C composites. Due to that, an attempt has been taken to optimize powder metallurgy process parameters on the mechanical properties. In general, a material should possess excellent hardness and compressive strength properties then only it can be used for desired application; according to that, this two mechanical properties have been studied by grey Taguchi method.

2. Experimental Details

In this investigation, AA8079 powder was produced by mingling the elemental powders Cu, Fe, Si, and Zn with Al powder. Purity of Al, Cu, Fe, Si, and Zn powders is 99.5%, and mesh size as 10 μm as AA8079 possesses less weight with high strength. B_4C was selected as reinforcement particle with 99.5% purity and mesh size as 10 μm as it has excellent hardness; in addition, it has less density, and it is the third hardest reinforcement next to diamond and cubic nitride. The chemical composition of the pure elemental powders is essential to synthesis AA8079 0.05Cu, 1.3Fe, 0.3Si, 0.15Zn, and Al remaining (each one in wt %). The SEM image of the produced AA8079 and as received B_4C is displayed in Figures 2(a) and 2(b).

Figure 3 shows the details of fabrication of ball milled aluminium alloy and its composites. The needed amount of elemental powders was exactly weighted by utilizing an electronic weight balance machine to produce the composition, AA8079, AA8079-5%B_4C, AA8079-10%B_4C, and AA8079-15%B_4C and ball milled via high energy ball mill for 10 h [22]. The drum speed maintained was 100 rpm [23]. The diameter of the steel ball utilized here was 10 mm, and ball to powder ratio was 10 : 1 [24].

The ball milled powders were compressed into cylindrical billets (Dia 24 × 10 mm). A computerized universal testing machine capacity of 10 ton has been used to acquire a green compact. Figure 4 shows the compaction press used and other testing process conducted for the present work. The green compacts were compacted at three different compaction pressure 200 MPa, 300 MPa, and 400 MPa. Then, the green compacts were sintered at three different sintering temperatures 375°C, 475°C, and 575°C at three different sintering times 1 h, 2 h, and 3 h. As per ASTM, E384-08 Vickers hardness test was performed at a load of 0.3 kg and a dwell time of 10 s on the samples [25], and as per ASTM, E9-89a compression strength test was done via computerized universal testing machine [26]. In this investigation, trials were carried out with four parameters, and three level have been selected. Hence, L27 orthogonal array was selected like reinforcement wt. %, compaction pressure, sintering temperature, and sintering time. Table 1 displays the process parameters and their levels, and the details of the experimental plan by means of L27 OA are enumerated in Table 2. Figure 5 shows the procedure followed for Taguchi grey relational analysis in this work.

3. Results and Discussions

3.1. S/N Ratio Analysis. Taguchi technique is a dominant utensil in value optimization for fabrication routes. Taguchi technique creates use of an unusual design of OA to inspect the worth characteristics over a nominal amount of experiments [27]. Word "signal" indicates the necessary value for the output characteristic, and "noise" indicates the horrible value for the output characteristic. The S/N ratios could be deliberate using Equations (1) and (2)

$$\frac{S}{N}\,\text{ratio} = -10 \log (\text{MSD}). \qquad (1)$$

MSD is mean square deviation.

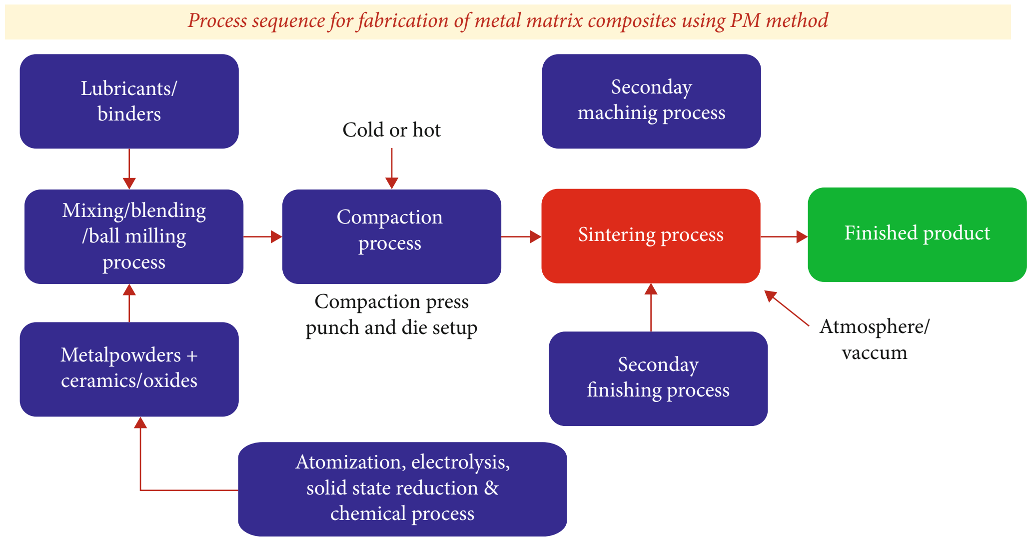
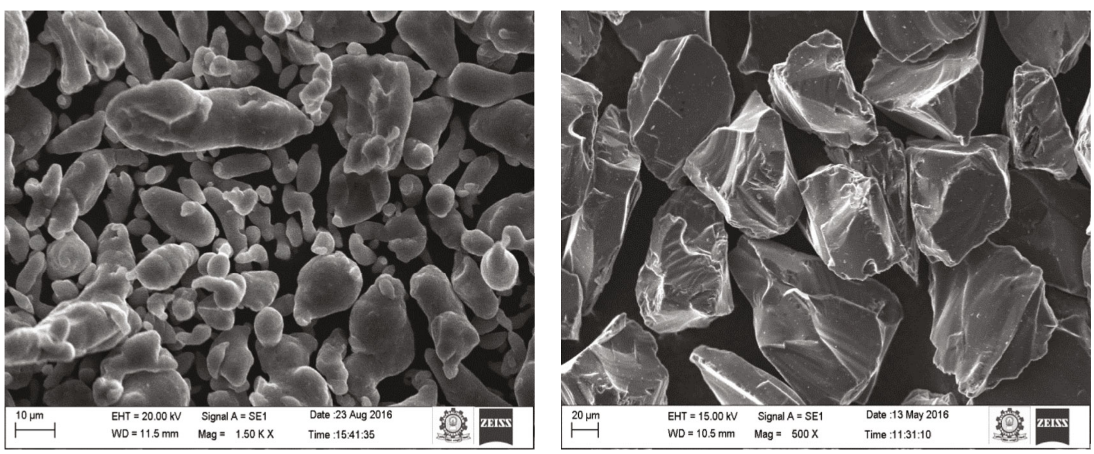


Figure 1: Process sequence for fabrication of MMC using PM.



(a) (b)

Figure 2: (a) SEM images of 10 h ball milled AA8079 powders; (b) as received B_4C.

Figure 3: Fabrication of ball milled aluminium alloy and its composites.

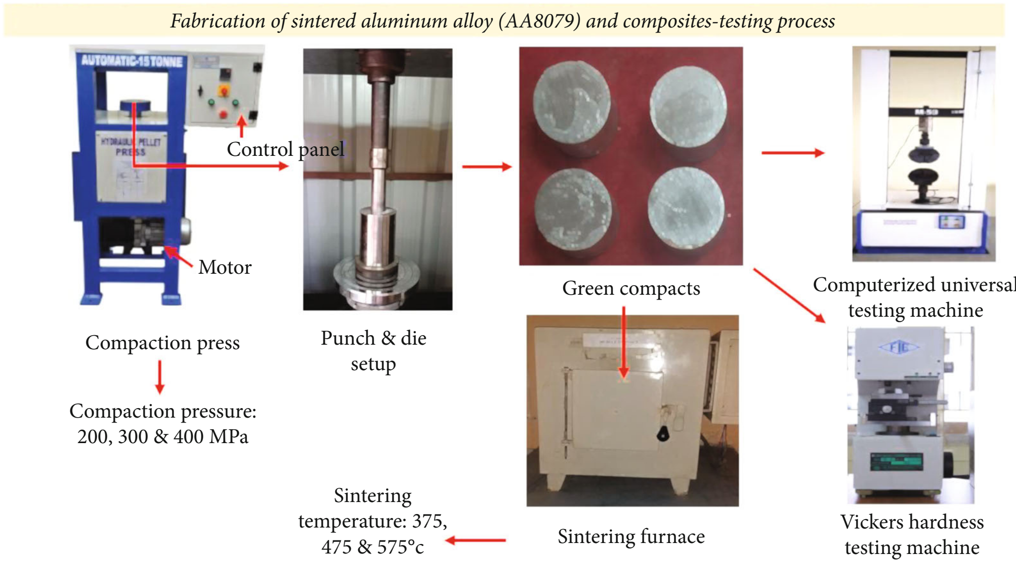


Figure 4: Powder metallurgy process to produce alloy and composite samples.

Table 1: Process parameters and their levels.

Symbols	Parameters	Unit	Level 1	Level 2	Level 3
A	Reinforcement wt.%	%	5	10	15
B	Compaction pressure	MPa	200	300	400
C	Sintering temperature	°C	375	475	575
D	Sintering time	hr	1	2	3

The MSD for the higher the better quality characteristic is expressed as

$$\mathrm{MSD} = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{T_i^2}. \quad (2)$$

An entire degree of factor was six to four factors. The tests would permanently be carried out extra in numbers than that of designated DOF. Therefore, L27 OA was chosen based as per Taguchi's design of experiments [28].

3.2. Interaction Effects of Factors. S/N response table for the microhardness and compressive strength is displayed in Table 3, and S/N response graph is shown in Figure 6, drawn via the results provided in Table 3. The microhardness and compressive strength increase with increasing the reinforcement wt %, compaction pressure, and sintering temperature [29, 30]. Here, the reinforcement wt % has been found to be the supreme active parameter and compaction pressure; sintering temperature and sintering time have been identified to be a slight consequence on mechanical properties founded on S/N ratio. From the Figure 6, it is clearly witnessed that reinforcement wt % is the major noteworthy factor on the response. It is detected that the interaction of reinforcement wt % with compaction pressure is minor at low sintering temperature and noteworthy at higher sintering temperature, the foremost cause is improper bind amid the particles at low compaction pressure and low sintering temperature; and repeatedly, it decreases the microhardness and compressive strength value of the composites. Interaction of compaction pressure with sintering temperature is minor at low pressure and important at higher pressure. The maximum microhardness and compressive strength are attained when the compaction pressure is higher at sintering temperature [31–35]. The interaction of sintering temperature with sintering time is major at maximum temperature and minor at least temperature for the microhardness, because diffusion of atoms takes place at maximum temperature [36]. They [37] reported that increase in reinforcement wt % and sintering temperature increases the microhardness of the composites. This work [38] reported that rise in compaction pressure and sintering temperature increases the compressive strength.

3.3. Grey Relational Analysis. It is one of the easiest and simplest tools to provide exact results. The values of grey relation coefficient, grey relation grade, and its rank of each experiments are arranged in Table 4. The author [39] reported maximum the grey relational grade; the superior would be the multirecital characteristics. Figure 7 displays interaction plot for grey relational grade. Figure 8 displays grey relational response for parameters for instance microhardness and compressive strength. The optimal parameter is acquired from trial 27. Table 5 displays response table of

Table 2: Experimental results as per L27 OA.

Expt. no	Reinforcement (wt%)	Compaction pressure (MPa)	Sintering temperature (°C)	Sintering time (hr)	Compressive strength	Hardness
1	5	200	375	1	125.49	141.59
2	5	200	475	2	133.74	145.27
3	5	200	575	3	140.05	120.09
4	5	300	375	2	131.48	147.92
5	5	300	475	3	149	149.73
6	5	300	575	1	142	167.3
7	5	400	375	3	105.33	151.25
8	5	400	475	1	156.03	114.89
9	5	400	575	2	157.11	112.62
10	10	200	375	1	108.09	138.97
11	10	200	475	2	110.81	164.85
12	10	200	575	3	151.24	136.06
13	10	300	375	2	112.79	120.45
14	10	300	475	3	145.98	128.53
15	10	300	575	1	154.77	154.7
16	10	400	375	3	116.22	122.02
17	10	400	475	1	141.06	152.38
18	10	400	575	2	148	132.41
19	15	200	375	1	139.09	161.56
20	15	200	475	2	120	126.42
21	15	200	575	3	122.12	165.98
22	15	300	375	2	147.19	145.69
23	15	300	475	3	150.06	184.41
24	15	300	575	1	156.88	159.14
25	15	400	375	3	145.02	151.77
26	15	400	475	1	164.33	174.2
27	15	400	575	2	171	158.03

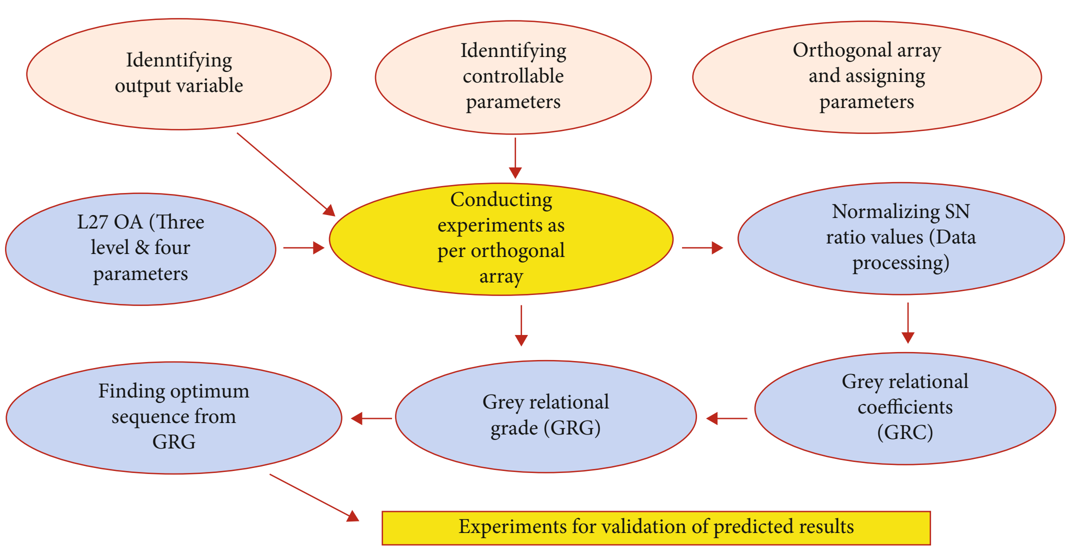


Figure 5: Procedure for Taguchi grey relational analysis.

Table 3: Response table normalized SN ratios.

Expt. no	Normalized S/N ratios	
	Microhardness	Compressive strength
1	0.403538	0.306989
2	0.454799	0.432618
3	0.104053	0.528704
4	0.491712	0.398203
5	0.516924	0.664992
6	0.761666	0.558398
7	0.538097	0
8	0.03162	0.772042
9	0	0.788488
10	0.367043	0.042028
11	0.727539	0.083448
12	0.326508	0.699102
13	0.109068	0.113598
14	0.221619	0.619004
15	0.586154	0.752855
16	0.130937	0.165829
17	0.553838	0.544084
18	0.275665	0.649764
19	0.681711	0.514086
20	0.192227	0.22339
21	0.743279	0.255672
22	0.460649	0.63743
23	1	0.681133
24	0.648001	0.784986
25	0.545341	0.604386
26	0.85778	0.898432
27	0.632539	1

the average grey relational grade for every level of the parameters. According to these stages, average grey relational grade has been identified; (i) grey relational grades have been combined via factor equal for every column in the orthogonal array and (ii) average obtained [40]. The abovementioned step has been repeated to determine the normal grey relational grade values for every level of the parameters. They [41] reported that average grey relational grade indicates the level of correlation amid reference sequence and the comparability sequence, the superior the value of the grey relational grade, the stronger the correlation to the reference sequence.

The optimal process parameter combination is achieved from Table 5. The optimal reinforcement weight percent level 3; optimal compaction pressure level 2; optimal sintering temperature, level 3 and duration, level 1; and the best combination of process parameters, A_3 B_2 C_3 D_1. The optimal process parameters values are reinforcement content 15 wt %, compaction pressure 400 MPa, sintering temperature 575°C, and sintering time 1 h. It could be understood from the Table 6 the maximum value is 0.1479, and the equivalent control factor, i.e., the reinforcement wt % has the strongest effect on multiperformance characteristics. The order of consequence of the process parameter is factor A (reinforcement wt %), B (sintering temperature), C (compaction pressure), and D (sintering time), i.e., 0.1479 > 0.1179 > 0.0907 > 0.0620. Factor A is utmost important influence in the process for the multiperformance characteristics.

3.4. ANOVA. From ANOVA in Table 7, it is detected that the reinforcement weight %, sintering temperature, and compaction pressure are vital parameters from the *F* values. The sintering temperature is the most second influential parameter. The compaction pressure has been considered as third dominant part on the responses. Reinforcement weight % is notable as utmost serious factor with highest contribution percentage as shown in Figure 9. The compaction pressure, sintering temperature, and sintering time are subsidized fair with contributions. Figure 9 shows the contribution plot for all the parameters drawn from ANOVA table.

Sintering normal for Al_2O_3-reinforced 2xxx series Al composite powders was explored to acquire improved densification. The dissemination of the fluid stage was speedier in the composite powder sintered example than in the mixed powder sintered example. The outcomes demonstrate that a more prominent measure of fluid stage is expected to improve the sinterability of 2xxx series Al composite materials [42]. From Tables 3–6, the ideal parameters for the compressive strength and hardness can be anticipated as the reinforcement weight 15%, compaction pressure 400 MPa, the sintering temperature 575°C, and the sintering time 1 h. This result is near the S/N and ANOVA comes about.

3.5. Confirmation Test. Five examples were finished with A3B2C3D1 parameters, and their normal quality coefficient was found. Table 8 reveals the relationship of the predicted quality coefficient and real quality coefficient of this composite preforms. A low rate blunder of 2.2% is gotten amid anticipated; what is more, trial esteem is demonstrating a decent relationship as appeared in Table 8.

3.6. Microstructure Analysis of the Composites Produced by Anticipated Parameters. SEM analysis had been conducted for the samples fabricated from the predicted parameters ($A_3B_2C_3D_1$), and the images are shown in Figures 10(a) and 10(b). From the SEM images, the occurrence of weight percentage of B_4C particles in the AA8079 matrix was attained. The foremost factors manipulating the microstructure of PM components are compaction pressure along with sintering temperature as per the results obtained from the present study. It is observed from Figures 10(a) and 10(b) that the higher compaction pressure and sintering temperature enhance proper bonding amid B_4C particles and AA8079 matrix. This creates denser structure owing to greater diffusion rates results in fine microstructure. The uniform distribution of B_4C particles in Figure 10(b) is evident in the proper identification PM parameters from the TGRA. This proper microstructure of the composite sample enhanced the properties such as CS and hardness.

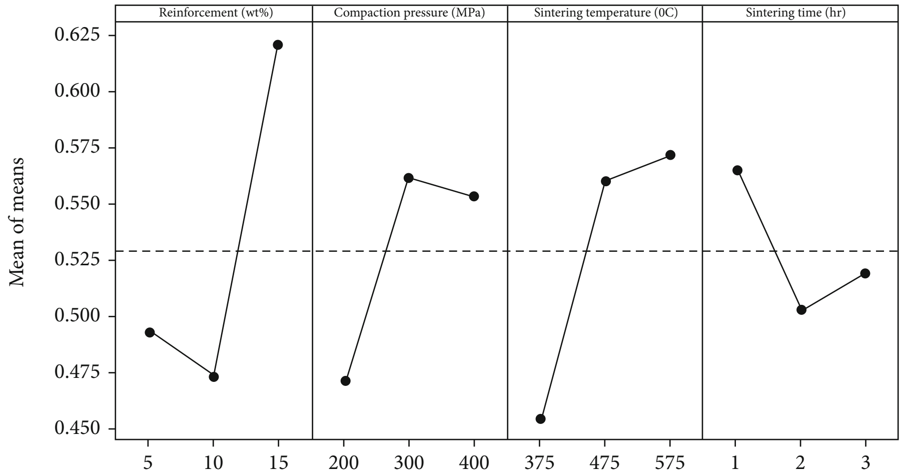


Figure 6: S/N ratio response graph for microhardness and compressive strength.

Table 4: Grey relational coefficient.

Expt. no.	Grey relation coefficient: Microhardness	Grey relation coefficient: Compressive strength	Grey relational grade	Rank
1	0.456012	0.419108	0.43756	22
2	0.478377	0.468436	0.473406	19
3	0.35818	0.514776	0.436478	21
4	0.49589	0.453804	0.474847	18
5	0.508608	0.598796	0.553702	8
6	0.6772	0.53101	0.604105	6
7	0.519803	0.333333	0.426568	23
8	0.340511	0.686853	0.513682	15
9	0.333333	0.702729	0.518031	14
10	0.441323	0.342942	0.392133	24
11	0.647282	0.35297	0.500126	16
12	0.426079	0.624299	0.525189	13
13	0.359471	0.360646	0.360059	27
14	0.39112	0.56754	0.47933	17
15	0.547138	0.669214	0.608176	5
16	0.365213	0.374765	0.369989	26
17	0.52845	0.523059	0.525755	12
18	0.408385	0.588072	0.498229	16
19	0.611031	0.507143	0.559087	7
20	0.382329	0.391662	0.386996	25
21	0.660746	0.401823	0.531284	10
22	0.481069	0.579663	0.530366	11
23	1	0.6106	0.8053	1
24	0.586855	0.699287	0.643071	4
25	0.523747	0.558276	0.541011	9
26	0.778549	0.831161	0.804855	2
27	0.576395	1	0.788198	3

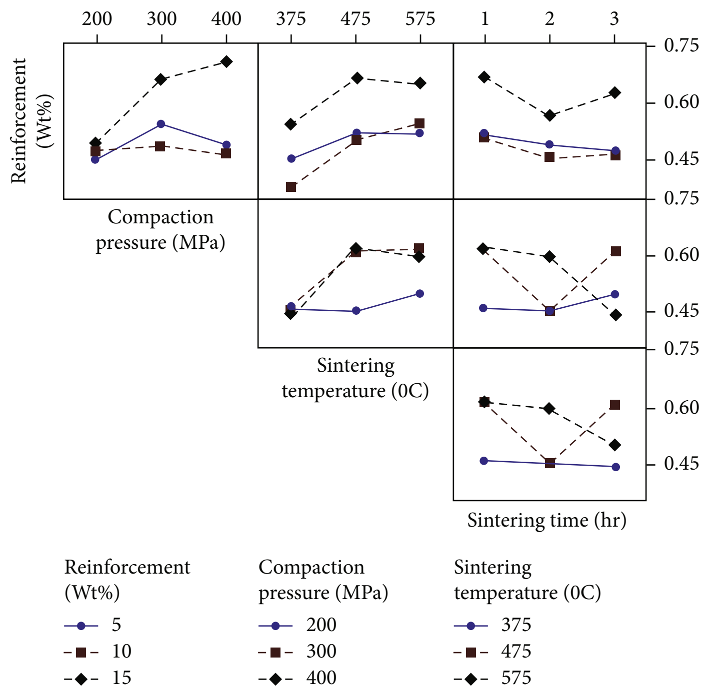


Figure 7: Interaction plot for grey relational grade.

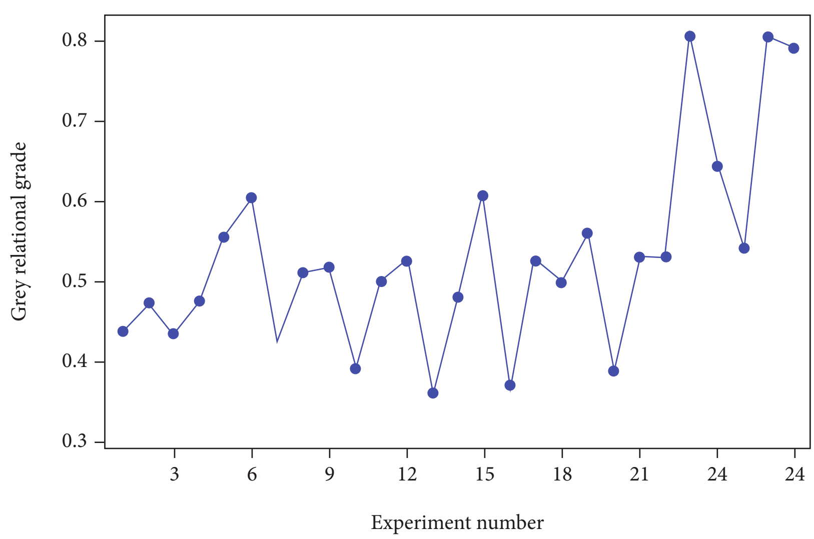


Figure 8: GRGs for response parameters (MH, CS).

Table 5: Grey relational grade for each level of parameters.

Factor	Parameters	Level 1	Level 2	Level 3	Delta	Rank
A	Reinforcement wt. %	-6.195	-6.622	-4.367	2.255	1
B	Compaction pressure	-6.601	-5.198	-5.384	1.403	3
C	Sintering temperature	-6.954	-5.269	-4.961	1.992	2
D	Sintering time	-5.128	-6.160	-5.896	1.032	4

Table 6: Response table for means.

Factor	Parameters	Level 1	Level 2	Level 3	Delta	Rank
A	Reinforcement wt. %	0.4932	0.4732	0.6211	0.1479	1
B	Compaction pressure	0.4714	0.5621	0.5540	0.0907	3
C	Sintering temperature	0.4546	0.5604	0.5725	0.1179	2
D	Sintering time	0.5654	0.5034	0.5188	0.0620	4

Table 7: Analysis of variance for grey relational grade, using adjusted SS for tests.

Source	DF	Adj SS	Adj MS	*F* value	*P* value
Reinforcement wt.%	2	0.115957	0.057979	8.61	0.002
Compaction pressure	2	0.045403	0.022702	3.37	0.057
Sintering temperature	2	0.075683	0.037842	5.62	0.013
Sintering time	2	0.018770	0.009385	1.39	0.274
Error	18	0.121183	0.006732		
Total	26				

$S = 0.0820511$; $R - Sq = 67.86\%$; $R - Sq(adj) = 53.57\%$.

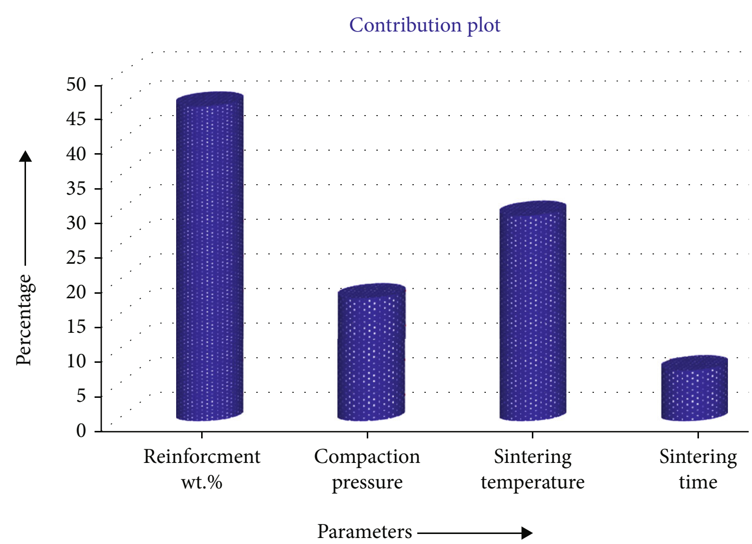
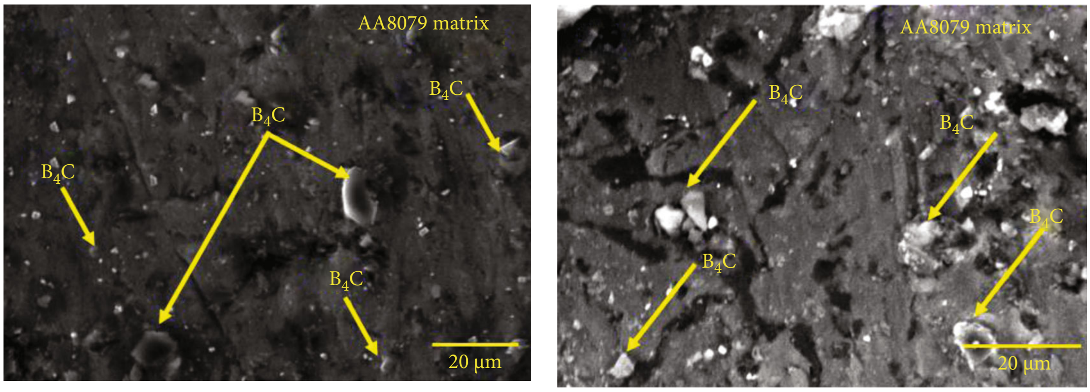


Figure 9: Contribution plot from ANOVA.

Table 8: Confirmation results.

	Optimal process parameters	
Parameter	Predicted	Experiment
Microhardness	$A_3B_2C_3D_1$	190 VHN
Compressive strength		177 MPa



(a) (b)

FIGURE 10: (a, b) SEM image of the AA8079-15%B_4C composites fabricated as per the optimized PM parameters.

4. Conclusions

The subsequent conclusions have been strained from the investigations conducted on the AA8079-B_4C composites under various process parameters.

The AA8079-B_4C composites were fabricated via powder metallurgy manufacturing method.

The influence of powder metallurgy process parameters on AA8079-B_4C composites was studied.

The important parameters reinforcement weight percentage, compaction pressure, sintering temperature, and sintering time were analysed by using Taguchi grey analysis on the responses such as hardness and compressive strength of AA8079-B_4C samples.

Amid the parameters, reinforcement weight percentage 15%, sintering temperature 575°C, compaction pressure 400 MPa, and sintering time 1 h shows a positive consequence on the mechanical properties.

SEM examination on the AA8079-B_4C sintered composites fabricated by the optimized parameters shows the homogenous dispersal of the reinforcement with the matrix and good bonding between the matrix and reinforcement.

In future, the same results were optimized by using some other optimization tools like genetic algorithm and neural network.

Data Availability

The data 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.

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