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Research Article

Experimental Investigation and Optimization of Material Removal Rate and Tool Wear in the Machining of Aluminum-Boron Carbide (Al-B_4C) Nanocomposite Using EDM Process

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Electrical discharge machining (EDM) is a cost-effective unconventional machining method used for machining any composites materials. EDM is based on the thermoelectric energy between the electrode and workpiece. In this work, boron carbide particles of 50 nm (6 wt.%) are reinforced with aluminum 7075 (94 wt.%) prepared using stir casting method. The stir casting process is carried out at speed of 700–800 rev/min. The fabricated aluminum-boron carbide nanometal matrix composites are used as workpiece (anode); copper electrode is used as tool (cathode). This work investigates the influence of EDM process parameters such as current (I), pulse on-time (t_{on}), and tool diameter (d) during machining of Al-B_4C composite on metal removal rate (MRR) and tool wear rate (TWR). The design of experimental plan is executed by Taguchi approach, and the responses of each parameter are influenced by analysis of variances (ANOVA). Response table for average value of MRR and TWR shows that the current is the significant parameter affecting MRR and TWR. From this work, it was observed that material removal rate increased with increasing the current, and the tool wear rate decreases.

1. Introduction

The input parameters were optimized by Box Behnken method, and quadratic model was suggested for output responses. The prepared specimen is machined using electrical discharge machining (EDM). The presence of graphite nanopowders in dielectric fluid notably improved the surface finish and enhanced MRR (material removal rate) and EWR (electrode wear rate) [1, 2]. The input process parameters were optimized using L18 orthogonal array of Taguchi Method on AISI D2 steel specimen machined by electrical discharge machining (EDM). The electrical spark vaporized on work material there after it has been flushed out through fluid medium. It has been observed that increasing current leads to increasing the surface roughness, and CuW electrode prepared through powder metallurgy is better than conventional Cu electrode [3, 4]. The silicon powder mixed in dielectric fluid gives more MRR and better surface roughness. EDM is a very important machining method that is extensively and effectively used for the machining of such materials, exactly and cost-effectively within the high advance in business [5]. The experimental investigation has different characteristics to reduce machining time and cost. Dry EDM milling obtained superior function compared to oil EDM milling and oil die sinking EDM. This paper work is about the reduction of tool wear rate using boron doped CVD-diamond (B-CVD) and polycrystalline diamond (PCD). The results show lack of knowledge in the process behavior of B-CVD and PCD in micro-EDM as well as wear on tool electrode with surface formation process [6, 7]. It is clearly evident that it is the toughest material, specifically having high magnetic permeability and being difficult to make microhole. Moreover, severe tool wear rate can be observed using conventional machining compared to micro-EDM process [8].

Rotation of tools provides adequate flushing in the machining zone compared to nonrotational tools. In general, the classical experiment is too difficult to optimize and very complex. This can be overcome using Taguchi method [9, 10]. MRR by sterilization conductor polarity on a zirconia-based composite offers the foremost stable machining conditions and terminates that negative polarity with a perceptibly lower risk of arcing. This experimental investigation brought a new concept such as mixing of micro-MoS_2 powder in dielectric fluid along with ultrasonic vibration using μ-EDM processes. However, the most significant process needs to increase MRR without degrading the surface finish [11, 12]. Al7075 is employed within the production of M16 rifles for the army vehicles. The M16 rifle prime quality has lower and higher receivers. Moreover, extension tubes, square measure, are usually made of 7075-T6 alloy. Due to its greater strength, superior hardness, thermal properties, and potential to be extremely polished, 7075 is widely utilized in molding tool. Boron chemical compound (B_4C) is one amongst the toughest materials known, ranking third behind diamond and cubical component compound. It is the toughest material created in tariff quantities. Boron chemical compound powder is created by reacting carbon with B_2O_3 in an electrical arc chamber, through carbothermal reduction or by gas section reactions. Nowadays, although metal matrix composites have more advantages, they are not widely used as their plastic counterparts. This paper presents getting precision machining obtained by smaller overcut dimensions of crater resulting in low MRR with less energy desirable [13, 14]. Many combinations of metals, ceramics, and compounds are often used with matrices of low temperature alloys. In most of the cases, Taguchi approaches were broadly used to find optimized result performed by different characteristics through significant parameters and reduced sensitivity of the system performance to design a top-quality system. The improvement is to select the required parameters for machining Ti-6Al-4V superalloy on micro-EDM by victimization of the Taguchi technique with different responses on MRR, TWR, overcut, and taper. They conjointly know optimum combination levels of victimization ANOVA and S/N quantitative relation graphs. The Taguchi technique spots the optimal value to extend the removal rate of material in which fluid containing micropowder in micro-EDM victimization associates degree L18 orthogonal array. The different results were observed on EDM machining with multiple characteristics of MRR value and surface roughness. Analysis of variance is employed to review the importance of variables method on gray relative grade showing discharged current and duty cycle being the most needed parameters [15, 16].

The mechanical properties of composite material have been improved by introducing fly ash material. Filler material such as potassium titanium chloride is used to avoid wettability issues. Modern composite materials attract significant attention compared with aluminum alloys due to their high specific properties, reduced weight, corrosion resistance, and cost reduction used for aircraft structural parts [17, 18]. Aluminum alloy 6063 reinforcement of TiB_2 shows lower wear rate by increasing the % of TiB_2 particles improving the peak hardness and good interfacial bond in situ composites method. A new stir caster setup is introduced in this experimental work to get homogeneous dispersion of aluminum-based SiC composite used by four bladed 45° angular, and its position is 35% of material below and 65% of material above the stirrer. Aluminum alloy AA7075 is reinforced with different ratio of TiB_2 fabricated using in situ reaction of organic salts K_2TiF_6 and KBF_4 to molten aluminum. It also increases the exothermic reaction holding time which improves wear resistance [19–21]. Aluminum-TiB_2 composite material specimens were prepared by powder methodology, and the experiment was conducted through hipping treatment to improve CTE results. Three different particle sizes of B_4C (56.9 μm, 4.2 μm, and 2.0 μm) are investigated to study the morphology behaviour using Al7075/B_4C composites by plasma activated sintering. A high performance of light weight composite armor is produced with B_4C composite metal foams having adequate potential applications prepared by PM technique [22, 23]. The MMC material is prepared with Al6061 and different % of rice husk to improve the wear resistance because it reduces the plastic deformation on the worn surface and size of wear debris generated. The results of this investigation showed the superiority of Al7075/Al_2O_3/5 wt% of graphite composites for gaining their wear reduction [24]. The influence of plasma-activated sintering parameters was studied using Al7075/B_4C precipitating smooth interparticle bonding. Tribological and mechanical properties were studied on Al7075/graphite composites for the optimum wear rate. The manufacturing of low-cost material is always in demand and needed in most of the engineering fields. Those demands are overcome by using fly ash material taken from industrial waste, agricultural waste, etc. This reinforcement of MMC obtained superior mechanical properties [25]. The fabrication of aluminum with B_4C occurs poor wetting condition during liquid stage. It can be avoided by introducing flux material such that K_2TiF_6 improves good interfacing bonding and wettability due to the presence of TiC and TiB_2. Mechanical, tribology, and microstructure of Al7075 reinforced with nanoparticles were studied. It has been observed that the porosity level and hardness increase by increasing the wt% of nanoparticles [26].

From the previous research, it was noticed that current, pulse on-time, and pressure were selected as electrical discharge machining parameters to obtain response parameters like material removal rate (MRR), tool wear rate, and surface roughness. As far as the optimization techniques related to Al-B_4C is concerned, researchers have mainly used response surface method. But the capability of other optimization techniques like Taguchi and ANOVA should also be examined. The present work is thus focused on EDM machining of aluminum-boron carbide composite. Stir casting method is used for fabricating aluminum-boron carbide (6 wt.%) with the particle size of 50 nm in Al7075 metal matrix. The effect of current, pulse on-time (T_{on}), and electrode diameter on MRR and TWR is investigated using Taguchi and ANOVA techniques. Experiments are performed as per L16 orthogonal array of Taguchi. The optimal setting of different process parameters is also found to maximize MRR and minimize EWR.

2. Experimental Setup

The experiments are conducted on the fabricated aluminum 7075 nano boron carbide metal matrix composites using EDM as shown in Figure 1. A mix between two propelled materials which are MMC of Al7075T6 as workpiece and copper I as terminal has been chosen in this investigation. The copper impregnated graphite is considered as a crossbreed material for the cathode, exponentially utilized as a part of hardware and shape making industry. The workpiece or occupation is secured and braced at a proper area on the x-y table [27]. The area of little gaps or fine profound openings to be penetrated might be set apart at work. The activity might be set with the assistance of dial stand and DRO. A reasonable anode of specific size and additionally a proper guide bramble are chosen, and the cathode is embedded into the hurl for holding it. The cathode is then tried for coolant stream at a weight of around 100 Kg/sq·cm. The cathode may now be positional on to occupation to begin drilling process.

Figure 1: Electrical discharge machine used for this investigation.

2.1. Stir Casting of Al-B_4C Composite. The composite materials were fabricated by stir casting process route [28]. Commercially available aluminum Al7075 was chosen as the matrix and B_4C 50 nm selected as reinforcement. By liquid casting technique, the aluminum metal matrix is melted in the temperature of 850° about 1 kg. The preheated stirrer is introduced in the melt when the temperature of the melt is about 30°C above the pouring temperature. Agitation of the melt is started, and the preheated B_4C of 6 wt.% is added as reinforcement. Aluminum requires a temperature as high as 1100°C for wetting the B_4C surface completely. Aluminum alloy 7075T6 (94 wt.%) reinforced with boron carbide (6 wt. %) with the size of 50 nm is used in the current investigation. For the stir casting process, 470 grams 27 × 10 × 06 cm chunk of aluminum 7075 and 30 grams of nano boron carbide are taken in two cauldrons. The aluminum 7075 is cut into a pack of little pieces with the goal that it can fit into the cauldron no 4. Boron carbide is the hardest conventional abrasives. Its Mohs hardness is 9.36, melting point is 2350°C, and density is 2.51 g/cm^3. The boron carbide is taken in a different way, and both cauldrons are put in the muffle furnace. The most extreme warming capacity of the suppress heater is 900°–950°C considering 7075 at 635°C for softening purpose of aluminum and the boron carbide nanopowder at 2763°C. The mute heater is exchanged, and it begins to warm the metal and the clay powder. The stirrer turns at the very least to the most extreme speed of 750 to 1000 rpm. The stirrer measurements are 200 mm with neck length of 10 mm diameter, and wing/cutting-edge measurements are 15 mm width, 25 mm length, and 10 mm breadth. After the liquid fluids are blended in the cauldron utilizing stirrer, it was warmed to accomplish liquid state in the suppress heater to 950°C. Then, it is removed from the heater, and a pink hued powder named coverall is included over the best so the blend holds its temperature. At that point, the blend is made in to specific shape for testing with dimensions of 100 mm × 100 mm × 10 mm; before the charge is filled in the die, the die is heated to around 32°C. Figure 2 shows the surface of aluminum-boron carbide nanometal matrix composites using stir casting method. The fabricated composite material is having superior mechanical strength due to having more flexural strength and improved hardness. It can be used for several applications such as aerospace, transport, and automobile industries. It is the least expensive and high-performance material because it is more flexible and reliable in the fabricated part.

2.2. Experimental Investigation. In this work, 16 holes were made on aluminum T6 alloy using EDM machine with the parameters of discharge current (7.5, 10, 12.5, 15 amps), pulse on-time (1, 2, 3, and 4 micro sec), and the tool diameter

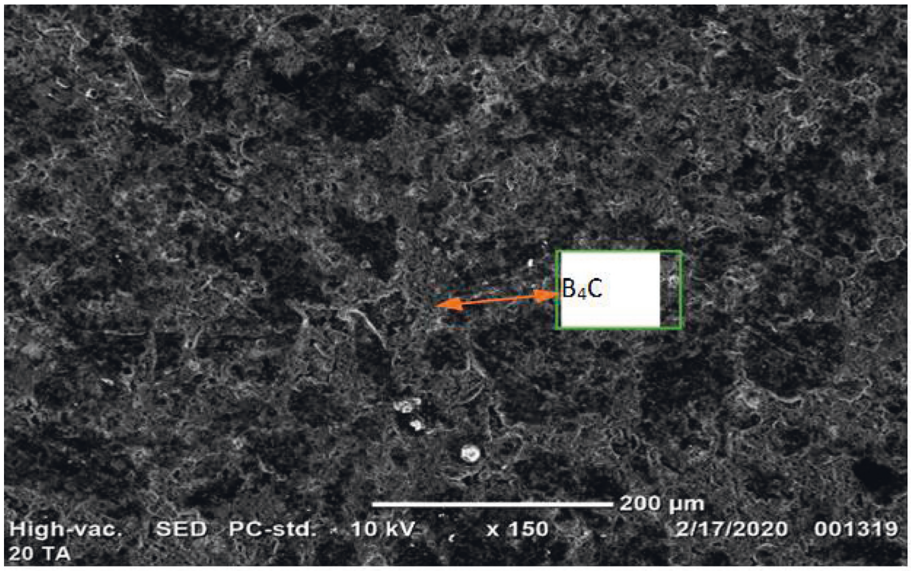

FIGURE 2: SEM images of fabricated aluminum (7075) B_4C nanocomposites.

(4, 6, 8, and 10 mm). Table 1 shows the electrical discharge machine input parameters and their levels. Figure 3 shows the machined samples and Figure 4 shows the tools used for this investigation [29].

2.3. ANOVA Method. In this work, it was embraced to decide the critical parameters impacting the unpleasantness in the MRF forms. The ANOVA is acquired by separating the deliberate aggregate of the squared deviations from the aggregate mean S/N proportion into commitments by every one of the control factors and the blunders. Table 2 demonstrates the outline of ANOVA for S/N proportions. Examination about the estimation of variety proportion (F), which is the fluctuation of the elements separated by the blunder difference for all control factors, demonstrated a considerably higher impact of pivoting speed and substantially less impact of cutting-edge by materials exploration infiltration profundity. The level of each factor commitment, P, on the aggregate of squared deviations from the aggregate mean S/N proportions delineated the level of impact on the outcome [30].

2.4. Mathematical Modelling and Optimization. The material removal rate and tool wear rate are conducted using fabricated composite material. The results of MRR as a function of tool diameter, current, and on-time were consolidated for machining optimization. This experiment is designed according to the selected 4 levels and 3 factors through the tools of Minitab software, and it is given in Tables 2–7. All the experimental results were analyzed by means of response surface methodology (RSM). RSM is the combination of mathematical and statistical technique which is used to model and analyze the problem. The main objective of the RSM is to optimize the response with respect to the given set of independent variables. ANOVA is a statistical tool which is used to investigate the nature of the input parameter and also identify which input parameter most significantly affects the output parameters. The mathematical expression for MRR and TWR for the composite material is shown in equations (1) and (2), respectively [31].

TABLE 1: Electrical discharge machining process parameters and their levels.

Electrical discharge process parameters	Levels			
	L1	L2	L3	L4
Tool diameter (mm)	4	6	8	10
Current (amps)	7.5	10	12.5	15
Pulse on-time (micro sec)	1	2	3	4

$$\text{Metal removal rate}\,(MRR) = \frac{W_1 - W_2}{T_d}, \quad (1)$$

where W1 is the weight of workpiece before machining, W2 is the weight of workpiece after machining, and Td is the time taken for machining.

$$\text{Tool wear rate}\,(TWR) = \frac{T_1 - T_2}{T_d}, \quad (2)$$

where W1 is the weight of tool before machining, W2 is the weight of tool after machining, and Td is the time taken for machining. The effects of input parameters of tool diameter, current, and pulse on-time and output parameters such as MRR and TWR are obtained during machining process and different outputs are found for different inputs.

3. Effect of Process Parameters on MRR

Electrical discharge machining was done on aluminum 70775 boron carbide nanometal matrix. Material removal rate was estimated, and the results were recorded in Table 8.

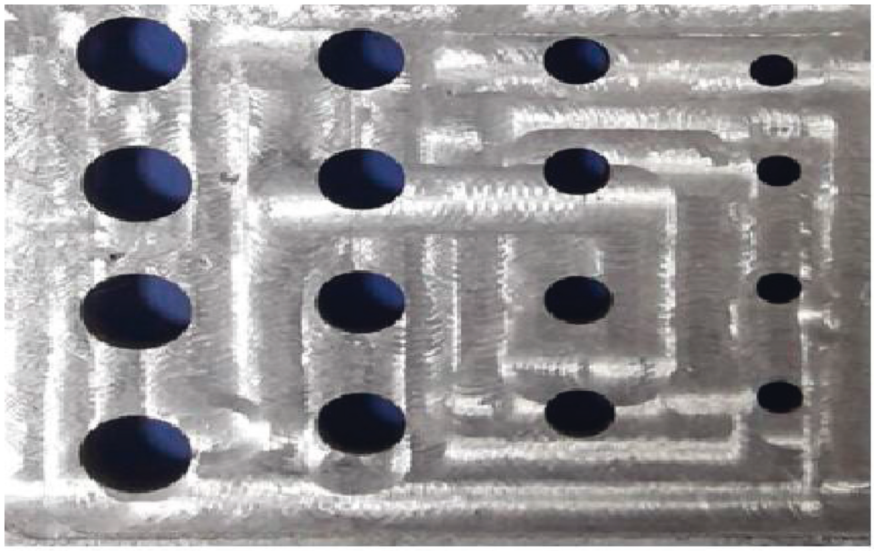

Figure 3: Holes made on T6 aluminum alloy.

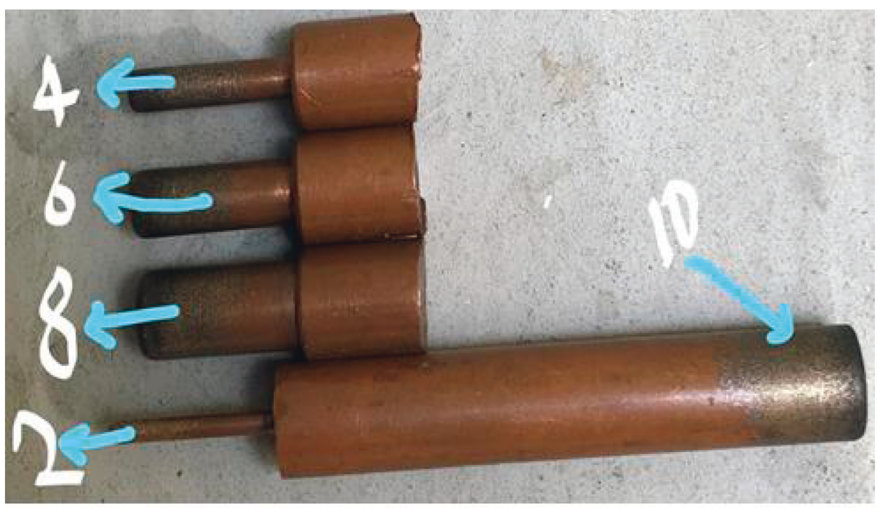

Figure 4: Tools used for EDM process.

Table 2: Larger S/N ratio Taguchi method.

Level	Tool diameter (mm)	Current (amp)	On-time (μ sec)
1	−53.10	−51.59	−50.09
2	−52.22	50.71	50.71
3	48.58	50.09	−51.59
4	48.58	50.09	−50.09
Delta	4.52	1.51	1.51
Rank	1	2	3

Table 3: Response table for means.

Level	Tool diameter (mm)	Current (amp)	On-time (μ sec)
1	0.002250	0.002750	0.003250
2	0.002500	0.003000	0.003000
3	0.003750	0.003250	0.002750
4	0.003750	0.000500	0.003250
Delta	0.001500	0.000500	0.000500
Rank	1	2	3

3.1. Effect of Tool Diameter on MRR. The material removal rate (MRR) has been increased by increasing current which is shown in Figure 5. Initially, there is no more effect on MRR in current 7.5 amps; thereafter, MRR rapidly increased from 0.039 mm to 0.252 mm obtained by increasing current in the range between 7.5 amps and 15 amps. In addition to this, MRR is more in the effect of current ranging between 10 amps and 15 amps [32].

3.2. Effect of Tool Diameter on MRR. TWR seems poor by using current in the range of 7.5–15 amps, as shown in Figure 6. The variations in tool diameter produced different MRR values. It was observed that there is no MRR by 2 mm diameter of tool due to more hardened precipitation matrix, and the MRR is attempted by 4 mm tool diameter [17, 18]. Again, the MRR value has effectively increased by increasing

Table 4: General linear model: MRR versus tool diameter, current, and on-time.

Factor	Type	Levels	Values
Tool diameter (mm)	Random	4	4, 6, 8, 10
Current (amp)	Random	4	1, 2, 3, 4
On-time (μ sec)	Random	4	1, 2, 3, 4

Table 5: Analysis of variance for MRR, using adjusted SS for tests.

Source	DF	Seq SS	Adj SS	Adj MS	*F*	*P*
Tool diameter (mm)	3	0.0536962	0.0536962	0.0178987	46.62	0.000
Current (amp)	3	0.0010337	0.030816	0.0010272	2.68	0.141
On-time (μ sec)	3	0.0073486	0.0073486	0.0024495	6.38	0.027
Error	6	0.0023035	0.0023035	0.0003839	—	—
Total	15	0.0643819	0.0941643	0.0217593	55.68	0.168

$S = 0.0195936$, R-Sq = 96.42%, and R-Sq (adj) = 91.06%.

Table 6: Smaller S/N ratio response for the Taguchi method.

Level	Tool diameter (mm)	Current (amp)	On-time (μ sec)
1	25.50	19.17	19.08
2	20.04	19.25	21.86
3	19.08	20.94	18.92
4	13.57	18.83	18.34
Delta	11.94	2.11	3.53
Rank	3	1	2

Table 7: Means response for the Taguchi method.

Level	Tool diameter (mm)	Current (amp)	On-time (μ sec)
1	0.05325	0.11775	0.12550
2	0.09950	0.12425	0.09075
3	0.12050	0.11100	0.13725
4	0.2125	0.13275	0.13725
Delta	0.15925	0.02175	0.04650
Rank	3	1	2

Table 8: MRR and TWR obtained during EDM of Al-B_4C.

S. no.	Tool diameter (mm)	Current (amps)	On-time (micro sec)	Wt. of W/P before (gm)	Wt. of W/P after (gm)	Wt. of tool before (gm)	Wt. of tool after (gm)	MRR (m^3/min)	TWR (m^3/min)
1	4	1	4	118.69	118.08	9.27	9.25	0.061	0.002
2	4	2	3	118.08	117.59	9.25	9.23	0.049	0.002
3	4	3	1	117.59	117.07	9.23	9.21	0.052	0.003
4	4	4	2	117.07	116.56	9.21	9.19	0.051	0.002
5	6	1	3	116.56	115.50	11.38	11.36	0.10	0.002
6	6	2	4	115.50	114.52	11.36	11.33	0.098	0.003
7	6	3	1	114.52	113.51	11.33	11.31	0.10	0.002
8	6	4	2	113.51	112.50	11.31	11.28	0.10	0.003
9	8	1	4	112.50	110.98	14.16	14.12	0.15	0.004
10	8	2	3	110.98	109.49	14.12	14.09	0.14	0.003
11	8	3	2	109.49	108.97	14.09	14.05	0.052	0.004
12	8	4	1	108.97	107.50	14.05	14.01	0.14	0.004
13	10	1	2	107.50	105.82	36.25	36.22	0.16	0.003
14	10	2	1	105.82	103.72	36.22	36.18	0.21	0.004
15	10	3	3	103.72	101.32	36.18	36.14	0.24	0.004
16	10	4	4	101.32	98.91	36.14	36.10	0.24	0.004

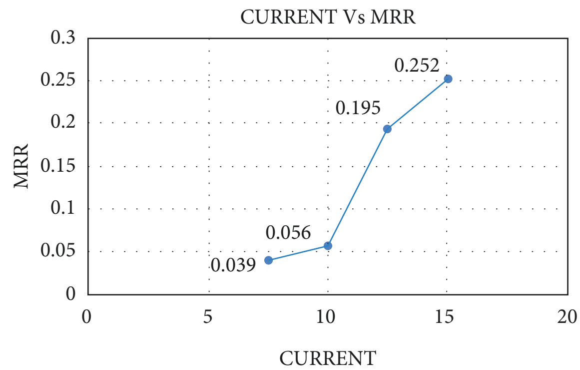

Figure 5: Current versus MRR.

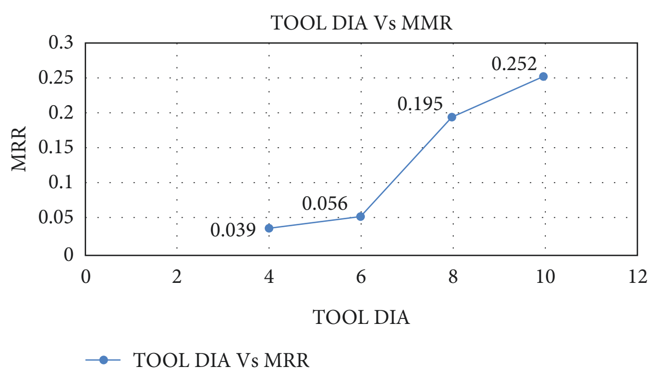

Figure 6: Tool DIA versus MRR.

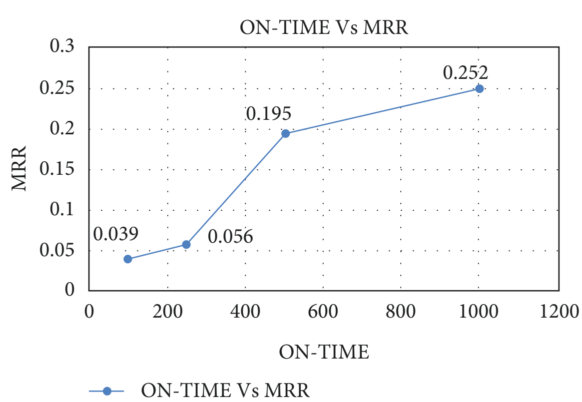

Figure 7: On-time versus MRR.

tool diameter 6 mm to 10 mm. The middle range of the current is more effective in gaining very less TWR. It can be obtained that the TWR values are having more variations with the current input.

3.3. Effect of On-Time on MRR. The MRR was also affected by on-time, as indicated in Figure 7 in the range from 100 to1000 μ·sec. MRR increases more between 400 and 600 μ·sec with increasing on-time sharply in the range from 200 to 500 μ·sec. The middle range of the on-time is more effective in gaining the high MRR than the first and last value [33]. It is shown that the MRR value is proportional to the on-time.

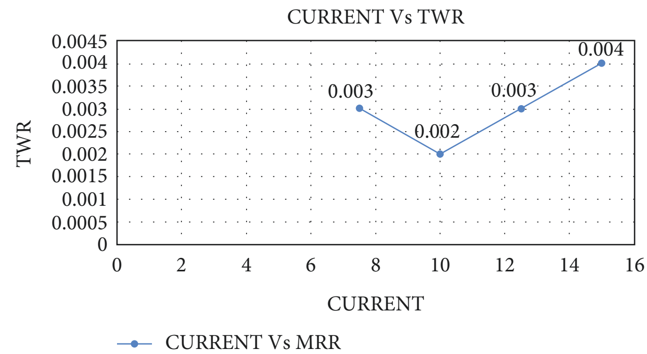

Figure 8: Current versus TWR.

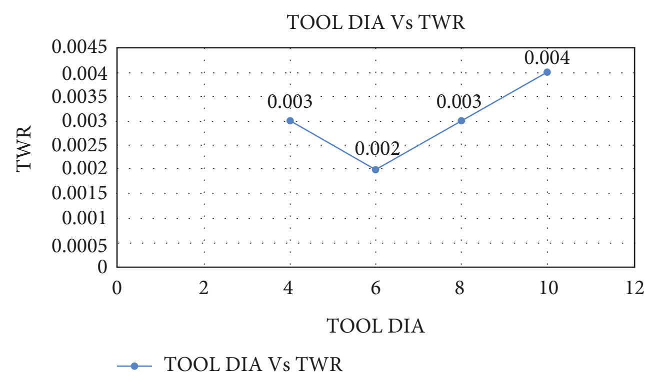

Figure 9: Tool diameter versus tool wear rate.

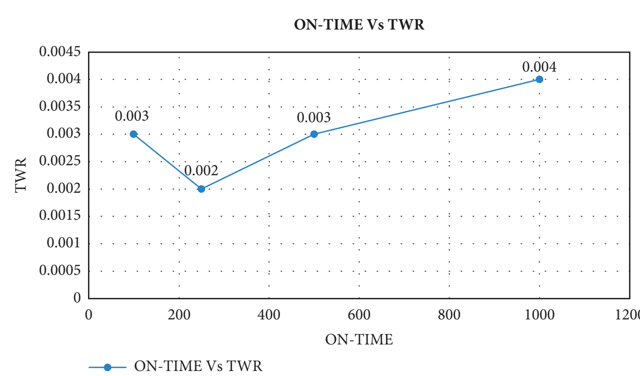

Figure 10: On-time versus TWR.

4. Effect of Process Parameters on TWR

Electrical discharge machining was done on the fabricated composites, and the electrode wear rate was calculated and recorded in Table 8.

4.1. Effect of Current on TWR. The effect of current on tool wear rate (TWR) is shown in Figure 8. TWR has been decreased at initial stage when the current ranged from 7.5 amps to 10 amps. The TWR was drastically increased (0.002 mm to 0.004 mm) by keeping on increasing current

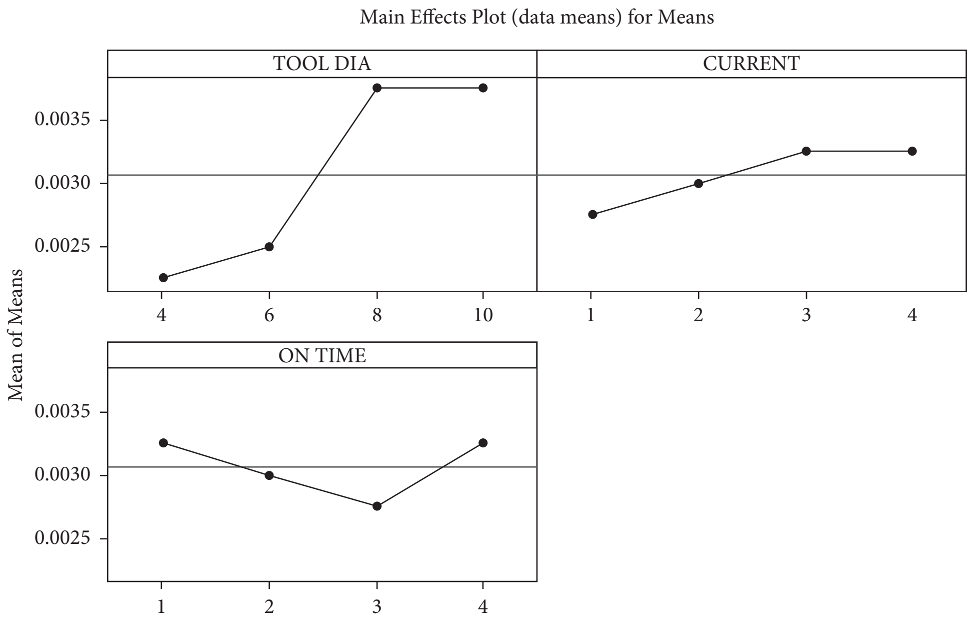

Figure 11: Main effect plot for means (ANOVA method).

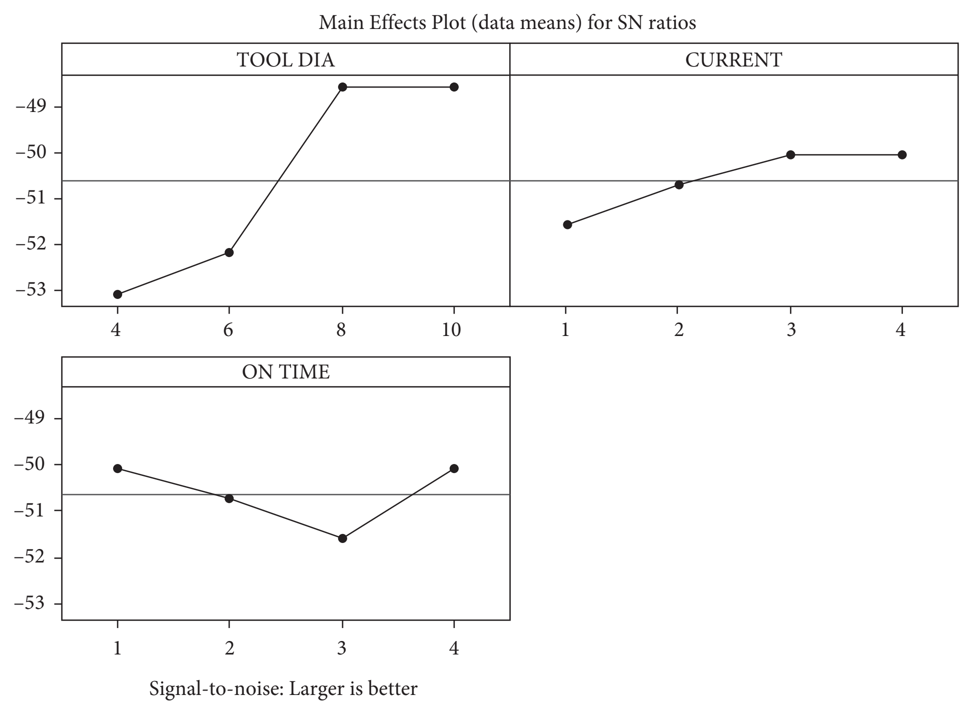

Figure 12: Main effect plot for SN ratio (ANOVA).

effect from 10 amps to 15 amps. It has been observed that one of the significant parameters was the current to control TWR [34].

4.2. Effect of Tool Diameter on TWR. The TWR was also affected by tool diameter as indicated in Figure 9. The variations of TWR have been observed by different tool diameters in the range from 4 mm to 10 mm. The less TWR was observed at 6 mm tool diameter, and more TWR was obtained in 10 mm tool diameter [23, 24]. Initially, it was noted that TWR decreased between 4 mm and 6 mm and after that increased. The middle range of the tool diameter was less effective and also gained less TWR, and the variation of TWR may be dependent on tool diameter [30].

4.3. Effect of On-Time on TWR. It was observed that TWR was also affected by on-time as represented in Figure 10 (ranging from 100 to 1000 μ·sec). TWR decreased with on-time ranging from 100 to 220 μ·sec. Moreover, it has been noted that TWR increased after decreasing as the function of

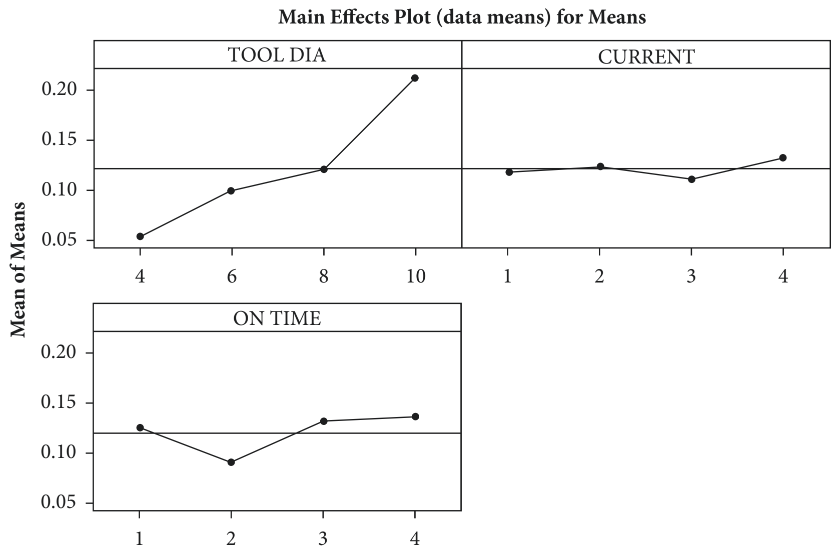

Figure 13: Main effect plot for mean.

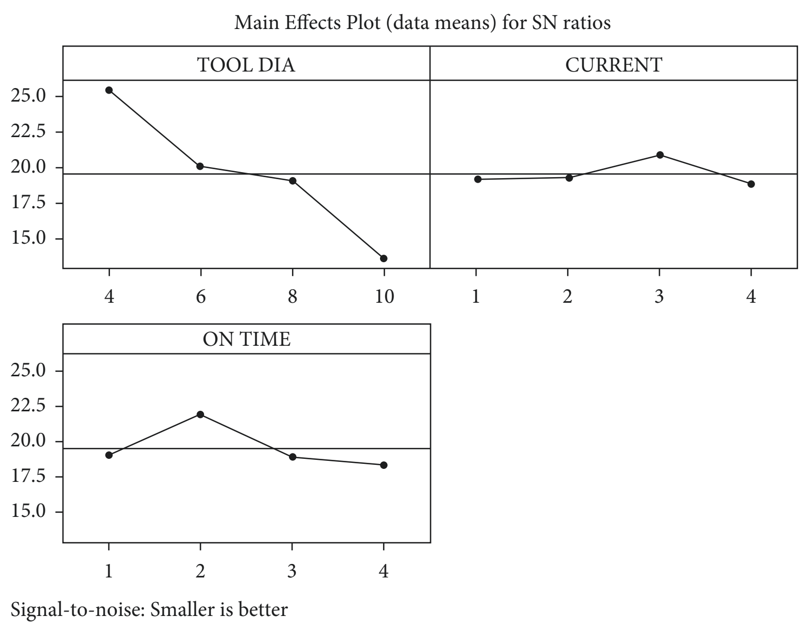

Figure 14: Main effect plot for S/N ratio.

on-time was in the range from 100 to 220 μ·sec. The middle range of the on-time was less effective and gained less TWR. It was shown that TWR obtained no significant result with the function of on-time at 220 μ·sec [19].

4.4. Optimization of Process Parameters. The analysis is based on S/N ratio and means as shown in Figures 11 and 12. This experimental work draws the effect of independent variables of tool diameter, current, and on-time for depending variables of MRR and TWR. Tables 2–7 provide the rank for the independent variables based on the response of MRR and TWR obtained in the prepared specimen. It is evident that the factors mainly considered are MRR and TWR. The concept of "larger is better" shows that the optimal parameter effect represents maximum MRR on the composite [27, 29]. According to this concept, the tool diameter plays a significant role in obtaining maximum material removal rate compared to factors influenced as current and pulse on-time. *F*-test value at 95% confidence level is used to indicate the independent parameters affecting the process. Analysis of variance for MRR using adjusted SS for tests provided that F-value is higher for tool diameter than other factors of machining. Under this optimal condition for minimum TWR, on-time plays a significant role followed by current then tool diameter.

It is evident that the optimum machining parameter is influenced by on-time with dependent parameters such as tool diameter as shown in Figures 11 and 12. Initially, the material removal rate is gradually increasing by varying tool diameter from 4 mm to 8 mm; after that, it maintains constant material removal rate from 8 mm to 10 mm. Furthermore, the MRR gets increased by keeping on increasing current up to a certain range; after that, it obtains constant current ranging from 3 amps to 4 amps. It has been observed that the MRR gradually decreases to the 1, 2, 3 μ·seconds ranges of pulse on-time; then, it increases by increment of 4 μ·sec as shown in Figures 13 and 14. For TWR, the requirement is to minimize in order to improve the machining efficiency. The criterion selected using the Minitab statistical software is "smaller is better," which states that the output must be as low as possible. The TWR is gradually decreasing by the increment of tool diameter, and also it has been observed that there is less tool wear in the parameter of pulse on-time followed by current obtained by ANNOVA results [33, 34].

5. Conclusion

In the present work, the machining optimization parameters, MRR and TWR, were carried out on Al7075T6 reinforcement of B_4C composite. The fabricated specimen reveals uniform distribution of B_4C particles and very low agglomeration and segregation of particles and porosity. Based on the experimental results, the following conclusions can be observed:

(i) MMC specimen prepared from reinforced particles of nano boron carbide and AL7075T6 weight fraction ranged between 6 wt.% and 94 wt.% using stir casting process.

(ii) The optimized machining parameters were found by Taguchi method in order to increase productivity and minimize production cost. The optimized parameters are tool diameter (10 mm), on-time (3 μ·sec), and current (3 amps) for greater MRR considered as larger value is better.

(iii) The optimum machining parameters were found by Taguchi method in order to reduce tool wear rate with adequate material removal rate which helps to improve modern manufacturing era. Two more combinations provided minimum tool wear rate during machining. Tool diameter (6 mm), pulse on-time (1 μ·sec), and current (3 amps) were considered among the significant factors for minimized TWR.

(iv) The mathematical model was used to determine the MRR and TWR on the fabricated composite material Al7075T6 with B_4C being in the combination of independent factors like tool diameter, current, and on-time.

(v) The analysis of variance (ANOVA) was used to analyze the experimental results to know the percentage of contribution of each parameter on MRR and TWR. The main effect plots for means were used to study the effect of input process parameters on EDM responses, while the S/N plots helped to decide the optimal level of process parameters and their values. The most significant parameter was tool diameter compared to other influenced factors for better metal removal rate, and the specified current range and pulse on-time were important for tool wear rate.

(vi) Under this optimum condition, the prepared MMC was subjected to homogeneous mixing and had superior mechanical properties. MRR was affected due to increase in the pulse off-time, which is dependent on the proportional to the pulse on-time. Increase in pulse on-time for all peak current settings led to increase in MRR and decrease in TWR.

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, they can be obtained from the corresponding author upon request.

Disclosure

This research was performed as a part of the employment of Hawassa University, Ethiopia.

Conflicts of Interest

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

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References

[1] L. Houman and E. C. Jameson, *Dearbern, Michigan, "Electrical Discharge Machining, Tooling, Methods and Applications*, pp. 5–19, Society of Manufacturing Engineers, Michigan, USA, 1983.

[2] M. P. Jahan, M. Rahman, and Y. S. Wong, "Study on the nano-powder mixed sinking and milling micro-EDM of WC-Co," *International Journal of Advanced Manufacturing Technology*, vol. 53, no. 1-4, pp. 167–180, 2011.

[3] N. Beri, S. Maheshwari, C. Sharma, and A. Kumar, *Performance Evaluation of Powder Metallurgy Electrode in Electrical Discharge Machining of AISI D2 Steel Using Taguchi Method*, International Journal of Mechanical and Mechatronics Engineering, 2008.

[4] B. R. Lazarenko, *To Invert the Effect of Wear on Electric Power Contacts,* Dissertation of the All-Union Institute of Electro Technique in Moscow/CCCP, Russian, 1943.

[5] W. J. Wang, P. Shen, J. H. Song, J. Guo, Q. Y. Liu, and X. S. Jin, *Experimental Study on Adhesion Behavior of Wheel/rail under Dry and Water Conditions*, pp. 2699–2705, Wear, 2011.

[6] Z.Bo Yu, J. Takahashi, and K. Masanori, "Dry electrical discharge machining of cemented carbide," *Journal of Materials Processing Technology*, vol. 149, pp. 353–357, 2004.

[7] E. Uhlmann and M. Roehner, "Investigations on reduction of tool electrode wear in micro-EDM using novel electrode

materials," *CIRP Journal of Manufacturing Science and Technology*, vol. 1, no. 2, pp. 92–96, 2008.

[8] H. S. Liu, B. H. Yan, F. Y. Huang, and K. H. Qiu, "A study on the characterization of high nickel alloy microholes using micro-EDM and their applications," *Journal of Materials Processing Technology*, vol. 169, no. 3, pp. 418–426, 2005.

[9] F. M. Hosking, F. F. Portillo, R. Wunderlin, and R. Mehrabian, "Composites of aluminium alloys fabrication and wear behaviour," *Journal of Materials Science*, vol. 17, no. 2, pp. 477–498, 1982.

[10] C. P. Hong, H. F. Shen, and I. S. Cho, "Prevention of macrosegregation in squeeze casting of an Al-4.5 wt pct Cu alloy," *Metallurgical and Materials Transactions A*, vol. 29, no. 1, pp. 339–349, 1998.

[11] T.-R. Lin, "Experimental design and performance analysis of TiN-coated carbide tool in face milling stainless steel," *Journal of Materials Processing Technology*, vol. 127, pp. 1–7, 2002.

[12] G. S. Prihandana, M. Mahardika, M. Hamdi, Y. S. Wong, and K. Mitsui, "Effect of micro-powder suspension and ultrasonic vibration of dielectric fluid in micro-EDM processes—Taguchi approach," *International Journal of Machine Tools and Manufacture*, vol. 49, no. 12-13, pp. 1035–1041, 2009.

[13] N. Tosun, C. Cogun, and G. Tosun, "A study on kerf and material removal rate in wire electrical discharge machining based on Taguchi method," *Journal of Materials Processing Technology*, vol. 152, no. 3, pp. 316–322, 2004.

[14] S. Mitra, G. Paul, and S. S. Nagahanumaiah, "Experimental study on influence of process variables on crater dimensions in micro-EDM of Y-Titanium aluminide"," *AIP Conference Proceedings*, pp. 1315–1181, 2011.

[15] M. S. Murali, G. B. Pavalarajan, and K. P. Rajurka, "A study on process parametrers of ultrasonic assisted micro EDM based on Taguchi Method," *Journal of Materials Engineering and Performance*, vol. 17, pp. 210–215, 2008.

[16] K. M. Patel, P. M. Pandey, and P. V. Rao, "Optimisation of process parameters for multi-performance characteristics in EDM of Al2O3 ceramic composite," *International Journal of Advanced Manufacturing Technology*, vol. 47, no. 9-12, pp. 1137–1147, 2010.

[17] V. Nishant, S. C. Vettivel, Characterization and experimental analysis of boron carbide and rice husk ash reinforced AA7075 aluminium alloy hybrid composite," *Journal of Alloys and Compounds*, vol. 741, pp. 981–998, 2018.

[18] T. Dursun and C. Soutis, "Recent developments in advanced aircraft aluminium alloys," *Materials and Design*, vol. 56, pp. 862–871, 2014.

[19] S. Natarajan, R. Narayanasamy, S. P. Kumaresh Babu, G. Dinesh, B. Anil Kumar, and K. Sivaprasad, "Sliding wear behaviour of Al 6063/TiB2 in situ composites at elevated temperatures," *Materials & Design*, vol. 30, no. 7, pp. 2521–2531, 2009.

[20] S. Manoj, D. Deepak Dwivedi, L. Singh, and V. Chawla, "Development of aluminium based silicon carbide particulate metal matrix," *Composite" Journal of Minerals & Materials Characterization & Engineering*, vol. 8, pp. 455–467, 2009.

[21] H. B. Michael Rajan, S. Ramabalan, I. Dinaharan, and S. J. Vijay, "Synthesis and characterization of in situ formed titanium diboride particulate reinforced AA7075 aluminum alloy cast composites," *Materials & Design*, vol. 44, pp. 438–445, 2013.

[22] C. Mallikarjuna, S. M. Shashidhara, U. S. Mallik, and K. I. Parashivamurthy, "Grain refinement and wear properties evaluation of aluminum alloy 2014 matrix-TiB2 in-situ composites," *Materials & Design*, vol. 32, no. 6, pp. 3554–3559, 2011.

[23] S. C. Tjong and K. F. Tam, "Mechanical and thermal expansion behavior of hipped aluminum–TiB2 composites," *Materials Chemistry and Physics*, vol. 97, no. 1, pp. 91–97, 2006.

[24] C. Wu, K. Ma, J. Wu et al., *Influence of Particle Size and Spatial Distribution of B_4C Reinforcement on the Microstructure and Mechanical Behavior of Precipitation Strengthened Al alloy Matrix Composites*, Materials Science and Engineering, Illinois, 2016.

[25] M. Garcia-Avila, M. Portanova, and A. Rabiei, *Ballistic Performance of Composite Metal Foams*, Composite Structures, California, 2015.

[26] J. Allwyn Kingsly Gladston, I. Dinaharanc, N. Mohamed Sheriff, and J. David Raja Selvam, *Dry Sliding Wear Behavior of AA6061 Aluminum alloy Composites Reinforced rice Husk Ash Particulates Produced Using Compocasting*, Journal of Asian Ceramic Societies, 2017.

[27] A. Baradeswaran, S. C. Vettivel, A. Elaya Perumal, N. Selvakumar, and R. Franklin Issac, *Experimental investigation on mechanical behaviour, modelling and optimization of wear parameters of B4C and graphite reinforced aluminium hybrid composites*, Materials and Design, vol. 63, pp. 620–632, 2014.

[28] A. Baradeswaran and A. Elaya Perumal, "Study on mechanical and wear properties of Al 7075/Al2O3/graphite hybrid composites," *Composites: Part B*, vol. 56, pp. 464–471, 2014.

[29] C. Wu, P. Fang, G. Luo et al., "Effect of plasma activated sintering parameters on microstructure and mechanical properties of Al-7075/B 4 C composites," *Journal of Alloys and Compounds*, vol. 615, pp. 276–282, 2014.

[30] A. Baradeswaran and E. Perumal, *Wear and Mechanical Characteristics of Al7075/Graphite Composites*, Composites: Part B, 2013.

[31] S. D. Saravanan and M. S. Kumar, "Effect of mechanical properties on rice husk ash reinforced aluminum alloy (AlSi10Mg) matrix composites," *Procedia Engineering*, vol. 64, pp. 1505–1513, 2013.

[32] G. Narasaraju and D. Linga Raju, "Characterization of hybrid rice husk and fly ash-reinforced aluminium alloy (AlSi10Mg) composites" materials today," *Proceedings*, vol. 3056, p. 3064, 2015.

[33] A. Baradeswaran and A. Elaya Perumal, "Influence of B4C on the tribological and mechanical properties of Al 7075–B4C composites," *Composites Part B: Engineering*, vol. 54, pp. 146–152, 2013.

[34] R. Amit, K. K. S. Mer, and P. Pawan Kumar, "Synthesis and characterization of mechanical, tribological and micro structural behaviour of Al 7075 matrix reinforced with nano Al2O3 particles," *Materials Today's Office: Proceedings*, vol. 4, pp. 2645–2658, 2017.