SSRG International Journal of Material Science and Engineering
ISSN: 2394–8884 / https://doi.org/10.14445/23948884/IJMSE-V10I3P102

Volume 10 Issue 3, 8-20, Sep-Dec 2024


*Original Article*

# Synthesis and Characterization of AL–SiC–B4C Hybrid Metal Matrix Composite

Soumyajeet Mohanty

*Mechanical Engineering Department, BPUT, Rourkela, India.*

*Corresponding Author : soumyajeetmohanty@yahoo.com*

Received: 08 September 2024 Revised: 17 October 2024 Accepted: 03 November 2024 Published: 16 November 2024

***Abstract -*** *In this study, the fabrication of Al-6061 + 10% wt. SiC + 10% wt. $B_4C$ and Al-7075 + 10% wt. SiC + 10% wt. The stir casting process does B4C hybrid MMC. The mechanical properties like tensile strength, maximum tensile strength and hardness are determined. EDM machining has been applied to both these fabricated specimens to obtain high product quality and improved performance levels. The copper electrodes have been used for EDM machining. Taguchi technique is implemented to framework the layout of the experiment. Current, voltage and pulse on time are taken as machining parameters, whereas MRR and surface roughness value are response or machining evaluation parameters. Anova optimization technique is implemented to determine the relative effect of machining parameters on the response parameters and also to determine the percentage contribution of all the factors of the selected machining parameters for MRR and surface roughness.*

***Keywords -*** *Al-6061+10%SiC+10%$B_4C$ & Al-7075+10%SiC+10%$B_4C$ Hybrid MMC, ANOVA analysis, EDM, Copper electrode, Taguchi analysis.*

## 1. Introduction

### *1.1. Materials*

A material is a matter or a substance that is purposed to be used for different applications in different fields of life (mostly solids are considered, and other condensed phases are also considered). In day-to-day life matter can be found in our physical world, starting from a shop or building to the astronomical research spacecraft. Matter can be generally divided into two parts: crystalline and non –crystalline [1]—for example, metals, polymers and ceramics. New, advanced and developed materials in the present scenario include nano-materials, semiconductors, biomaterials, etc. Historical eras were given their name based on the significant material found in that era, like the Stone Age, followed by the Bronze Age, Iron Age and the Steel Age, from where the manufacturing of ceramics and its related derivative metallurgy originates. Material science is marked as the oldest form of applied science and technology.

### *1.2. Composite Materials*

Composite material is a material composed of two or more physically and/or chemically distinct phases (matrix phase and reinforcing phase). It possesses bulk properties significantly different from those of any of the constituents [2].In other words, Composite material is defined as the mixture of two or more chemically and physically dissimilar elements arranged properly, and it has unique properties with respect to different constituent parts. In general, composites consist of matrices and reinforcements, primarily added to enhance the matrix strength and its other properties. The material used as a matrix should bind firmly to the reinforcing phase in position. The most common man-made composites can be divided into three groups: i) Polymer Matrix Composites (PMCs), ii) Metal Matrix Composites (MMCs), and iii) Ceramic Matrix Composites (CMCs) [3]. In particular, the MMCs play an important role in engineering and in advancing the manufacturing field to meet the growing and extraordinary demands raised by modern technology. The developments in aerospace, advancing activities in the aircrafts field, and the automotive industry emerge as such a demand. Further, MMCs have a relatively low specific gravity, which formulates their superior properties, particularly in modulus and strength, compared to many conventional engineering materials. After thoroughly studying the basic behaviour of materials and understanding their properties, it is now possible to design and develop a new composite material with improved mechanical and physical properties.

The new advanced materials are mainly composites, which give better output and performance. Therefore, the demand is continuously increasing due to the development of technology, which has led to the use of composite materials in various structural and industrial applications and diversified fields of society. The composite material is said to be a MMC if the matrix is metal or an alloy. The problems related to conventional materials are less load-carrying capability and poor performance at high-temperature applications. To avoid this shortcoming, MMCs are developed.

### *1.3. Fabrication Methods*

Fabrication of MMCs is the primary processing route of its production. The fabrication methods are broadly divided into three categories such as liquid state fabrication, solid-state fabrication and vapour state fabrication [4].

#### *1.3.1. Liquid State Fabrication*

MMCs fabricated in the liquid state find wider application due to their intrinsic worth and low cost of getting liquid metals compared to metal powder. The probability of fabricating a different complex profile using liquid metals with substantial ease is achieved by implementing developed or conventional methods in practice in casting technology. The researchers reported that the techniques used for fabricating MMCs in the liquid state are squeeze casting, compo casting, infiltration, spraying, in-situ fabrication, dispersion, and stir casting [4].

#### *1.3.2. Solid State Fabrication*

Solid-state fabrication of MMCs is generally used to obtain a good mechanical property. This process is implemented to get fine grain control in composite microstructure and the dispersion of reinforcements. In particular, the discontinuous reinforced MMCs are produced by this route to attain improved mechanical behaviour[4].

#### *1.3.3. Vapor State Fabrication*

In this kind of MMC fabrication technique, the matrix material is deposited from the vapour phase to different reinforcement. It is understood that less or no mechanical disturbance exists in the interfacial area, and improved adhesion is achieved between the matrix and reinforcements [4].

### *1.4. Selection Procedure*

#### *1.4.1. Matrix Material*

The matrix for the composite material must be chosen carefully in relation to its properties and the reinforcement nature. As it is the principal constituent in MMCs, the matrix alloy should be selected only after carefully studying its chemical compatibility with reinforcements. Many researchers have proposed a lot of matrix materials depending on their properties. Aluminium, titanium and magnesium are widely used among these available materials. Beryllium is the lightest structural material available and has a greater tensile modulus compared to steel. As Beryllium is brittle so, it is not suitable for the use of general applications. Though Mg is light, it is more reactive in nature than oxygen. Al is one of the most excellent choices available for matrix, due to its better mechanical properties, with high corrosion resistance, high toughness and also low density [10]. In addition, Al is cheap when compared to other light elements. Thus, aluminium-based MMCs offer potential in the area where advanced structural applications, good wear resistance at elevated temperatures, and enhanced mechanical properties are significant [5].

#### *1.4.2. Reinforcements*

The material used as reinforcement increases the stiffness and strength of the composite but sideways reduces the density of MMCs. To have better properties, reinforcement selection is an important part, and the selection of reinforcement depends on the type, size of particle reinforcement, processing technique and its chemical compatibility when added to a metal matrix.

Reinforcements are categorized based on their shape, dimension, property, weight, volume fraction and uniform dispersion in the matrix. Better improvement is obtained in properties with the introduction of fibre reinforcements; the prepared materials are not isotropic. However, particle-reinforced MMCs have the advantages of isotropic properties and are cost-effective [6]. If two or more two reinforcements are added to the matrix, it becomes a hybrid composite.

In addition, the existing fabrication techniques, together with hot forging, hot rolling, hot extrusion and machining, can be used for fabrication followed by finishing the composite materials. It has been proved that the effective reinforcement materials for aluminium and aluminium alloy are ceramic particles, enhancing mechanical properties [9]. In general, these ceramics are carbides, oxides and nitrides in nature. The general ceramic elements used are Silicon Carbide (SiC), Aluminium Oxide ($A1_2O_3$) [8], Titanium Di-boride ($TiB_2$), Boron Carbide ($B_4C$), thorium and graphite [17].

Sequentially, to develop a material with improved mechanical properties along with high thermal conductivity, graphite is the choice as reinforcement for MMCs. On the other hand, poor wet ability between the reinforcement and aluminium leads to difficulties in manufacturing the material at high temperatures [7]. SiC is a gifted reinforcement used in high-temperature structural materials, creep and corrosion resistance materials [11]. $B_4C$ reinforced composites are used in the nuclear sector applications, as they have good neutron absorbing capability [12].

### *1.5. Objectives of the Research Work*

- To fabricate Al –10 wt. % SiC–(10 wt. %) B4C reinforced composites through stir casting process and to ensure the uniform dispersion of reinforcement particles in the matrix.
- To determine the mechanical properties of the composites, such as tensile strength, yield strength, and hardness of the materials.
- To carry out electrical discharge machining on composite by using electrodes and to find out the MRR and Surface Roughness Value.
- The optimal level of addition of B4C particles and the significant role of individual input parameters on the response characteristics will be determined using ANOVA.

## 2. Materials and Methods

### *2.1. Materials*

*2.1.1. Aluminium Alloys*

The effective way to reduce the weight of any structure is to build it with materials of low specific weight. Aluminium alloys are metallic materials. As they provide a number of interesting mechanical and thermal properties, they are mostly used in various applications. In addition, aluminium shaping is easy, especially regarding material removal, such as machining. In other words, aluminium alloys are considered the group of materials that offer the highest levels of machinability compared with other lightweight metals like magnesium and titanium alloys.

*2.1.2. Silicon Carbide*

- Silicon carbide is considered one of the few lightweight covalently bonded ceramics. It was originally produced by a high-temperature electrochemical reaction of sand and carbon.
- The density is 3.208g/cm3, and the Mesh size is 80.
- SiC comprises tetrahedral carbon and silicon atoms with strong bonds in the crystal lattice and has a molecular weight of 40.10.
- The melting point of SiC is 2730°C, and the hardness is 3850kg/mm2.
- SiC is used as an excellent abrasive particle and has been produced and made into grinding wheels and abrasive products. It is not affected up to 800°C by any alkalis, acids, or molten salts. SiC forms a protective silicon oxide coating at 1200°C in air, which can be used up to 1600°C.
- The high strength and high thermal conductivity coupled with low thermal expansion give exceptional thermal shock-resistant qualities to SiC. Due to its low electrical conductivity, this material is used in resistance heating elements such as electric furnaces and as a key component in thermistors. SiC has high hardness, high strength, and low density, and hence, it is used in various high-performance applications. The new composite material reinforced with SiC particles is being developed for usage in structural engineering and wear applications.

*2.1.3. Boron Carbide*

- Boron Carbide is one of the hardest materials available in commercial quantities. The Mohs hardness of B4C is 9.5, and its melting point is around 2450°C.
- Its density is 2.52gm/cm3, and Vickers hardness is 3850kg/mm2.
- Boron carbide has a complex crystal structure. Due to its hardness and very low density, it has found application as a reinforcing agent for aluminium in military armor and high-performance bicycles, and its wear resistance has made it be employed in sandblasting nozzles and pump seals.
- Being a neutron absorber, boron carbide is used in powdered or solidified form to control the fission rate in nuclear reactors.

### *2.2. Experimental Process*

The present thesis work is based on the preparation of a Metal Matrix Composite made of Aluminium (6061 grade), Silicon Carbide (10%), Boron Carbide (10%) and Aluminium (7075 grade), Silicon Carbide (10%) and Boron Carbide (10%) by the stir casting process. After the preparation of MMC, the MRR is calculated from the readings taken through the EDM machining process.

Its surface roughness through the surface roughness meter and various mechanical properties will be studied on its recasting layer. Hence, the objectives obtained from the literature survey will be studied.

*2.2.1. Procedure for Fabrication of Aluminium-10%Silicon Carbide-10%Boron Carbide (Both Grades Of Aluminium-6061 And 7075)*

- The composite consists of aluminium alloy 6061 and 7075 cast as matrix (as shown in Figure 1), SiC (as shown in fig.2), and $B_4C$ (as shown in Figure 3) as reinforcement materials. The suitable fabrication technique for particle-reinforced metal matrix composite is the conventional stir casting route.
- As it is comparably low-cost and offers a wide selection of materials. Further, it produces better bonding of reinforcements with the matrix due to the uniform stirring action.
- The Al alloy 6061 kept in a crucible is heated in a resistance furnace at around 450°C for 1 hour before melting. In order to oxidize the surface of the reinforcements, SiC and $B_4C$ particles are preheated (as shown in Figure 4).
- Similarly, Al alloy 7075 kept in a crucible is heated in a resistance furnace at around 450°C for 1 hour before melting. In order to oxidize the surface of the reinforcements, SiC and $B_4C$ particles are preheated (as shown in Figure 5).
- The preheated aluminium is further heated above its liquidus temperature to melt the alloy completely. They are then slightly cooled below its liquidus to keep the slurry in the semisolid state.
- The heated particles are added gradually and mixed partially by manual stirring at an average speed for 5-10 minutes. The melt is maintained at 750°C ±10°C temperature range and the pouring temperature is around 720°C (as shown in Figure 6).
- The uniformly mixed molten state of the metal is poured into a sand mould (as shown in Figure 7) and allowed to cool to obtain the product. Hence, following the above process for fabrication of Al-6061 and Al-7075 Hybrid Metal Matrix Composite is produced. Here, the Aluminium grades are used as matrix whereas silicon carbide with 10% weight and boron carbide with 10% weight are used as reinforcements (as shown in Figures 8 and 9)


**Fig. 1 Aluminium 6061 And 7075 Grade Used for Fabrication**

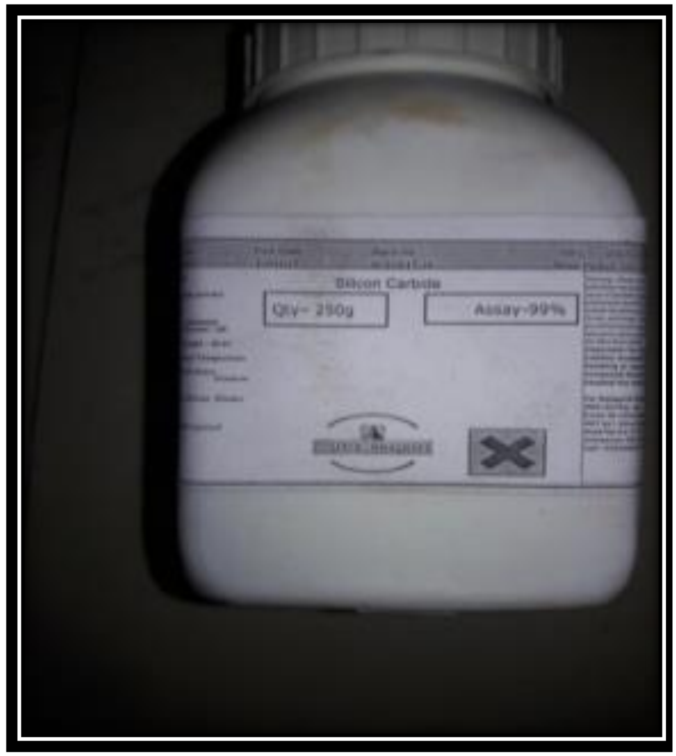


**Fig. 3 Silicon carbide**

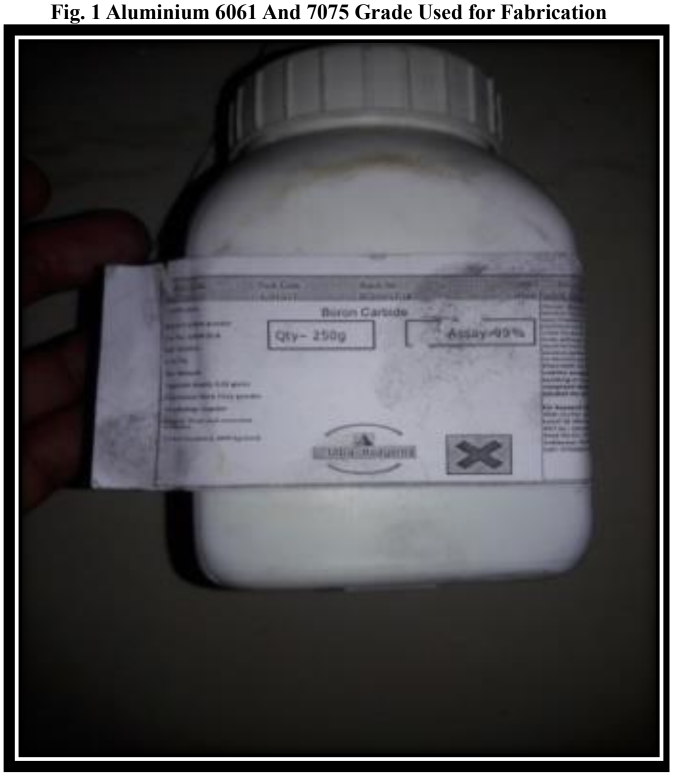


**Fig. 2 Boron carbide**

**Fig. 4 Aluminium 6061 In the Molten State**

**Fig. 5 Aluminium 7075 in the Molten State**

**Fig. 6 Mixture of Aluminium + 10% Sic + 10% $B_4c$ To Be Poured into Sand Mould**

**Fig. 7 After the Mixture Is Poured in The Sand Mould**

**Fig. 8 Formed Aluminium 6061 Hybrid Metal Matrix Composite**

**Fig. 9 Formed Aluminium 7075 Hybrid Metal Matrix Composite**

**Fig. 10 Al-6061 After Edm Operation**

**Table 1. Tensile test result of Al-6061 Hybrid Mmc**

| Tests | Value |
|---|---|
| Tensile Strength | 16.920KN |
| Ultimate Tensile Strength | 53.858N/mm² |

**Table 2. Tensile test result of Al-7075 Hybrid Mmc**

| Tests | Value |
|---|---|
| Tensile Strength | 88.40KN |
| Ultimate Tensile Strength | 281.640N/mm² |

**Table 3. Rockwell hardness result**

| Tests | Value |
|---|---|
| Rockwell Hardness Number for Al-6061 Hybrid Mmc | 90 |
| Rockwell Hardness Number Al-7075 Hybrid Mmc | 86 |

### *2.3. Machining Operation*

*2.3.1. Lathe Machining Operation*

The lathe is a machine tool used principally for shaping pieces of metal by causing the workpiece to be held and rotated by the lathe while a tool bit is advanced into the work, causing the cutting action. In the 4-jaw lathe machine, the following operations were carried out for the mechanical testing of Al-6061 and Al-7075 hybrid metal matrix composites. The turning operation is carried out, followed by the taper turning, to get the required dimensions for tensile specimen testing. Then, to make the surface smooth, a grinding operation is performed [18].

*2.3.2. Universal Testing Machine*

A universal testing machine, also known as a universal tester, materials testing machine or materials test frame, is used to test materials' tensile strength and compressive strength.

*2.3.3. Rockwell Hardness Test*

The hardness of the above-prepared Al-6061 and Al-7075 hybrid MMC is measured by the Rockwell Hardness tester, and the results are shown in Table 3.

From the table, it is observed that the Rockwell hardness number of Al-6061 hybrid MMC is greater than that of Al-6061 hybrid MMC.

*2.3.4. EDM Machining Operation*

In the experimentation process, the copper electrode removes materials from my Al-6061 and Al-7075 Hybrid MMC [20]. The copper tool (as shown in Figure 26) is used as a cathode, whereas the workpiece is used as the anode. The dielectric fluid used in the machining process is kerosene.

The mechanism of EDM is melting and vaporization. The material removal takes place due to high temperature (10000-12000ºC) generation on electrodes (workpiece and tool) caused by ionization (spark generation) in between electrode gaps [13]. The specimen after EDM operation is shown in Figures 11 and 12.

## 3. Design of Experiment (doe), Result and Discussion

Design of Experiment (DOE) is a scientific approach to simultaneously study the effect of multiple variables. DOE has the advantage of a smaller number of experiments required for preciseness, which affects estimation and improves the quality of a product or process [16]. In EDM, a number of control factors collectively determine the output responses [19]. Hence, in the present experimentation, one statistical technique called the Taguchi method is used to optimize the process parameters, leading to the improvement in the quality characteristics of the part under study [21]. The most important step in the DOE lies in selecting the control factors and their levels [22]. The EDM process has a large number of parameters. However, three machining parameters, namely, discharge current (Ip), voltage (V) and pulse-on-time (Ton), are identified and set at three levels after the literature survey, as shown in Table 4. The L9 orthogonal arrangement is shown in Table 5. For further experimental process, the L9 Orthogonal Array has been selected, as shown in Table 5.

**Table 4. Selected levels for taguchi analysis**

| Factors | Units | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Current (Ip) | [ampere] | 5 | 10 | 15 |
| Voltage (V) | [volt] | 20 | 25 | 30 |
| Pulse On Time (Ton) | [ µs ] | 100 | 150 | 200 |

**Table 5. L9 Orthogonal array arrangement required for taguchi analysis in design of experiment**

| Run No. | Current (Ip) | Voltage (V) | Pulse On Time (Ton) |
|---|---|---|---|
| 1 | 5 | 20 | 100 |
| 2 | 5 | 25 | 150 |
| 3 | 5 | 30 | 200 |
| 4 | 10 | 20 | 150 |
| 5 | 10 | 25 | 200 |
| 6 | 10 | 30 | 100 |
| 7 | 15 | 20 | 200 |
| 8 | 15 | 25 | 100 |
| 9 | 15 | 30 | 150 |

### *3.1. Performance Analysis Using Taguchi's s/n Ratio*

Taguchi method uses a statistical tool to measure performance characteristics known as the Signal-to-Noise (S/N) ratio to find out the optimum settings for the design parameters, and it (S/N ratio) consists of both the mean and the variability of performance characteristics [23]. There are three criteria of signal-to-noise ratios which are Lower-The-Better (LTB), the Higher-The-Better (HTB), and nominal-the-best (NTB) [23]. In present work experimentation, two responses are considered, i.e. Material Removal Rate (MRR) and Surface Roughness (Ra).

Lower the Better or Smaller, the Better is given as:

$$\frac{S}{N} ratio = -10\log\left[1/\text{n}\sum \text{y}^2\right]$$

Higher The Better or Larger, the Better is given as:

$$\frac{S}{N} ratio = -10\log\left[1/\text{n}\sum 1/\text{y}^2\right]$$

The Smaller the Better criterion is used to analyze the Surface Roughness Value [14], and The Higher The Better criterion is used to analyze the Material Removal Rate [15].

Steps for Taguchi Analysis using Steps for Taguchi Analysis using Minitab software:

- First, the Taguchi design is created by selecting the "stat" option from the menu option bar.
- While creating the Taguchi design, the orthogonal array is selected according to the selected parameters taken for the experimentation. In my present work, the L9 orthogonal array is selected as the number of parameters selected is three, and the number of factors is three.
- Then the factors are entered according to their values taken.
- After this, the L9 orthogonal array is displayed on the worksheet of Minitab software. After that, the response parameters are entered along with their values. In my present work, Roughness Value and MRR are selected as response parameters.

**Table 6. Tabulation of Taguchi Analysis (Final Result Obtained After the Taguchi Analysis of Design of Experiment for Aluminium - 6061 Hybrid Mmc in Tabulation Format)**

| Current | Voltage | T(On) | Roughness Value | Mrr | Snra1 | Mean1 | Snra2 | Mean2 |
|---|---|---|---|---|---|---|---|---|
| 5 | 20 | 100 | 5.382 | 15.7079 | -14.6189 | 5.382 | 23.9224 | 15.7079 |
| 5 | 25 | 150 | 7.039 | 11.7809 | -16.9502 | 7.039 | 21.4236 | 11.7809 |
| 5 | 30 | 200 | 5.374 | 7.8539 | -14.6060 | 5.374 | 17.9017 | 7.8539 |
| 10 | 20 | 150 | 4.291 | 58.9048 | -12.6512 | 4.291 | 35.4030 | 58.9048 |
| 10 | 25 | 200 | 4.903 | 53.9174 | -13.8092 | 4.903 | 34.6346 | 53.9174 |
| 10 | 30 | 100 | 4.478 | 23.0322 | -13.0217 | 4.478 | 27.2467 | 23.0322 |
| 15 | 20 | 200 | 5.860 | 46.7498 | -15.3580 | 5.860 | 33.3956 | 46.7498 |
| 15 | 25 | 100 | 5.032 | 24.9332 | -14.0348 | 5.032 | 27.9356 | 24.9332 |
| 15 | 30 | 150 | 4.632 | 12.3879 | -13.3154 | 4.632 | 21.8600 | 12.3879 |

**Table 7. Response Table For S/N Ratio for Surface Roughness (Al-6061 Hybrid Mmc)**

| Response Table for Signal to Noise Ratios | | | |
|---|---|---|---|
| Smaller is better | | | |
| **Level** | **CURRENT** | **VOLTAGE** | **T(ON)** |
| 1 | -15.39 | -14.21 | -13.89 |
| 2 | -13.16 | -14.93 | -14.31 |
| 3 | -14.24 | -13.65 | -14.59 |
| Delta | 2.23 | 1.28 | 0.70 |
| Rank | 1 | 2 | 3 |

Main Effects Plot for SN Ratios for Surface Roughness (Al-6061 Hybrid Mmc)

**Table 8. Response Table For S/N Ratios for MRR (Al-6061 Hybrid Mmc)**

| | Response Table for Signal to Noise Ratios | | |
|---|---|---|---|
| | Larger is better | | |
| **Level** | **CURRENT** | **VOLTAGE** | **T(ON)** |
| 1 | 21.08 | 30.91 | 26.37 |
| 2 | 32.43 | 28.00 | 26.23 |
| 3 | 27.73 | 22.34 | 28.64 |
| Delta | 11.35 | 8.57 | 2.42 |
| Rank | 1 | 2 | 3 |

Main Effects Plot for SN Ratios for MRR (Al-6061 Hybrid MMC)

*3.1.1. All Results Obtained from Taguchi Analysis for Design of Experiment (Al-6061 Hybrid Mmc)*

From the Taguchi Analysis of the design of the experiment,

The optimum Surface Roughness value from the S/N criterion (smaller the better ) is found at Current= 5 ampere, Voltage= 30 volt and T(on)= 200.

Here, the S/N ratio is nearly equal to the predicted value of the Taguchi Analysis.

Predicted value for the S/N ratio is -15.1048

And at the optimum level, the S/N ratio is -14.6060

The optimum Material Removal Rate value from the S/N criterion (larger the better ) is found to be at Current= 15 ampere, Voltage= 20 volt and T(on)= 200.

Here, the S/N ratio is nearly equal to the predicted value of the Taguchi Analysis.

Predicted value for the S/N ratio is 33.1206.

At the optimum level, the S/N ratio is 33.3956.

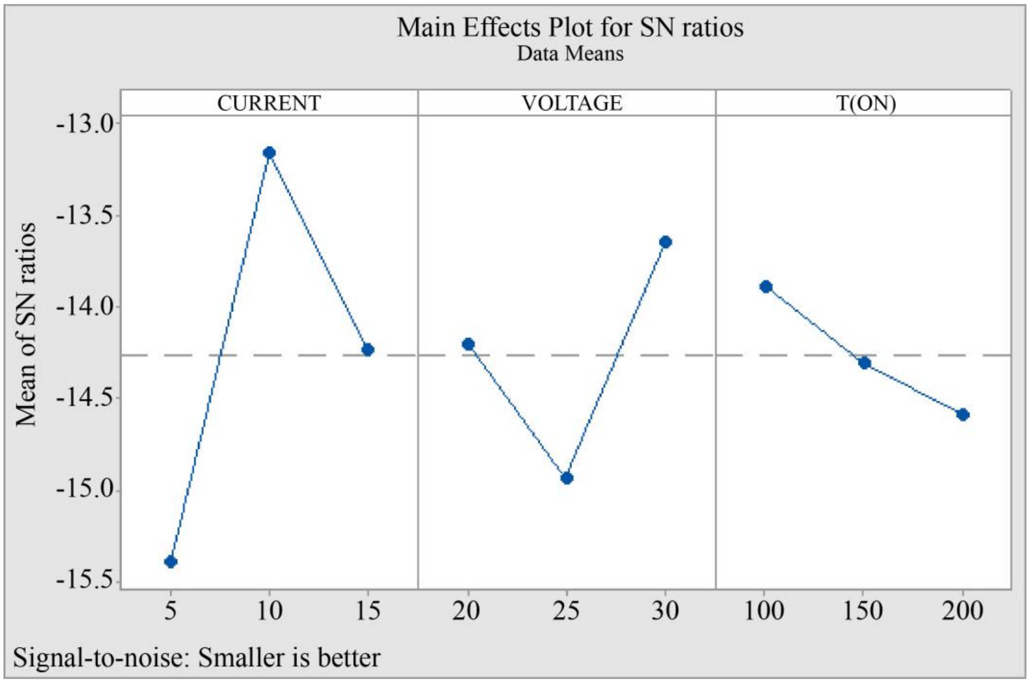


**Fig. 13 SN ratio plot for "ra"**

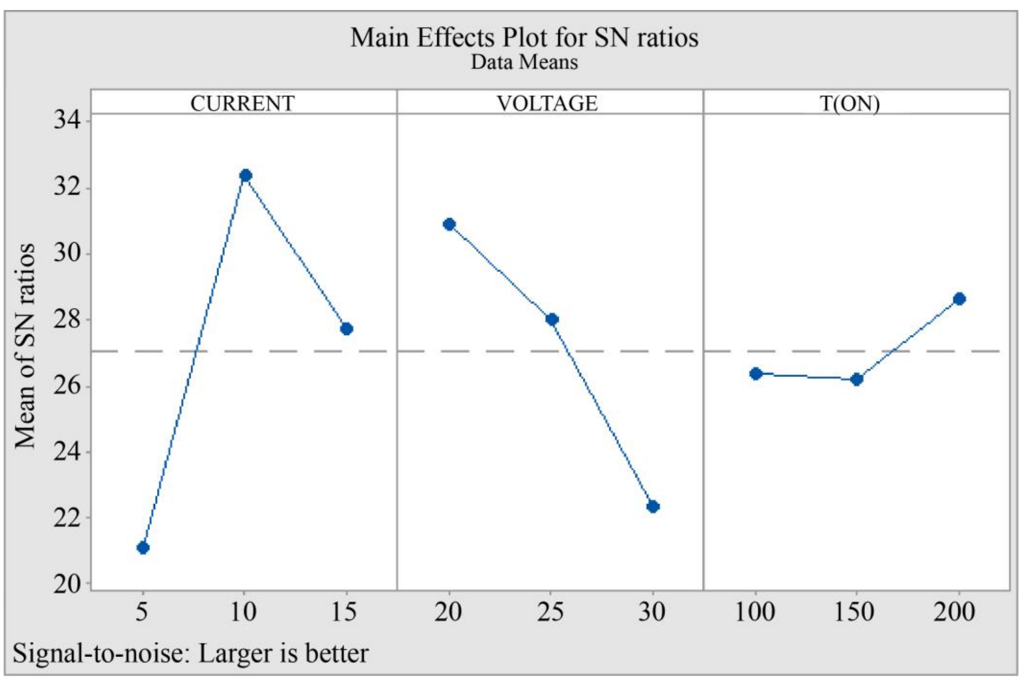


**Fig. 14 SN ratio for "MRR"**

*3.1.2. All Results Obtained from the Anova Analysis of Parameters are Given in the Table 9, 10 and 11.*

**Table 9. Anova result for al-6061 hybrid mmc for "ra"**

| Roughness Value(Ra) | Results |
|---|---|
| Ra Versus Current | In Aluminium-6061 grade the surface roughness is found to be maximum during the beginning of the machining when the current provided is 5ampere and gradually decreases when the current provided is 10ampere and increases again when 15ampere current is provided. So, the surface roughness is found to be minimum at 10ampere. |
| Ra Versus Voltage | In the Aluminium-6061 grade, the surface roughness is found to be maximum during the transition period of the machining when the voltage provided is 25 volts, and it is found to be minimum at 30 volts. |
| Ra Versus T(On) | In Aluminium-6061 grade, the surface roughness is found to be maximum during the end period of the machining when the T(on) provided is 200 microseconds and is found to be minimum at 100 microseconds. |

**Table 10. Anova result for al-6061 hybrid mmc for "mrr"**

| Material Removal Rate (Mrr) | Results |
|---|---|
| Mrr Versus Current | In Aluminium-6061 grade, the maximum MRR rate in current is found to be 10ampere and the lowest MRR rate in current is found to be 5ampere. |
| Mrr Versus Voltage | In the Aluminium-6061 grade, the maximum MRR rate in voltage is found to be 20 volts and the minimum MRR rate in voltage is found to be 30 volts. |
| Mrr Versus T(On) | In Aluminium-6061 grade, the maximum MRR rate in T(on) is found to be 200 microseconds, and the minimum MRR rate in T(on) is found to be 100 microseconds. |

**Table 11. Anova Result For Percentage Contribution Of Factors For Al-6061 Hybrid Mmc**

| Response Factors | Results |
|---|---|
| Surface Roughness | The highest contributing factor is found to be the current 61.41% value, which affects the surface roughness value. The contributing factor of voltage and T(on) is found to be 14.33% and 13.26% respectively. |
| Material Removal Rate | The highest contributing factor is found to be current, with a 60.85% value, which affects the MRR. The contributing factors of voltage and T(on) are found to be 35.57% and 3.44%, respectively. |

Taguchi Analysis Result Obtained on the Project Sheet of the Minitab Software for Al-7075 Hybrid MMC

**Table 12. Response Table for S/N Ratios for Surface Roughness (Al-7075 Hybrid MMC)**

| | **Response Table for Signal to Noise Ratios** | | |
|---|---|---|---|
| | **Smaller is better** | | |
| **Level** | **Current** | **Voltage** | **T (On)** |
| 1 | -11.61 | -13.21 | -14.98 |
| 2 | -15.89 | -16.31 | -13.41 |
| 3 | -14.40 | -12.37 | -13.51 |
| Delta | 4.28 | 3.94 | 1.58 |
| Rank | 1 | 2 | 3 |

Main Effects Plot for SN Ratios for Surface Roughness (Al-7075 Hybrid MMC)

**Table 13. Response Table for SN Ratios for MRR (Al-7075 Hybrid MMC)**

| | **Response Table for Signal to Noise Ratios** | | |
|---|---|---|---|
| | **Larger is better** | | |
| **Level** | **Current** | **Voltage** | **T (On)** |
| **1** | 24.05 | 32.84 | 26.69 |
| **2** | 33.31 | 29.13 | 33.43 |
| **3** | 31.09 | 26.49 | 28.33 |
| Delta | 9.26 | 6.35 | 6.74 |
| Rank | 1 | 2 | 3 |

Main Effects Plot for Sn Ratios for Mrr (Al-7075 Hybrid Mmc)

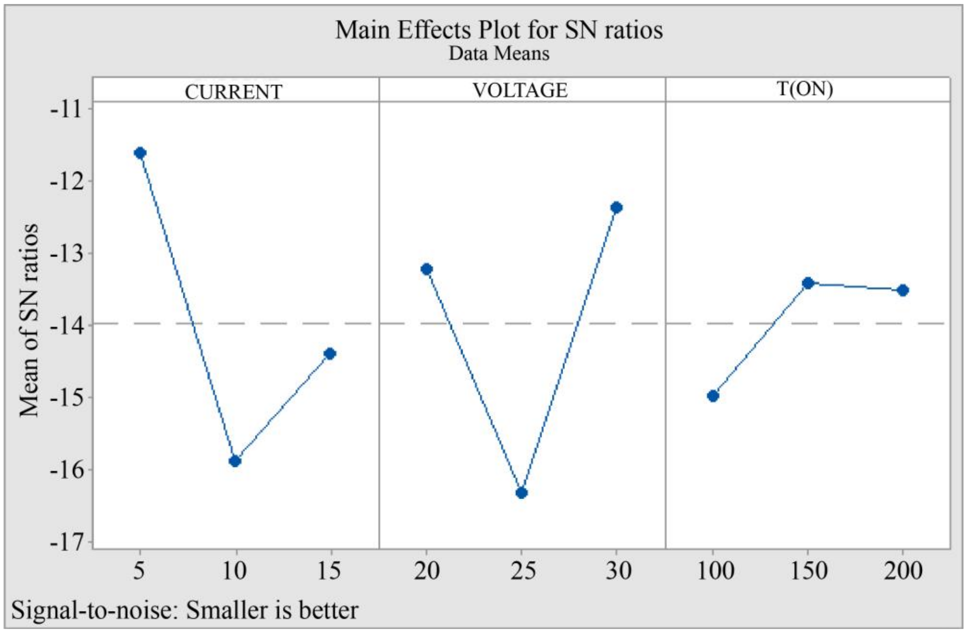


**Fig. 15 SN ratio plot "ra"**

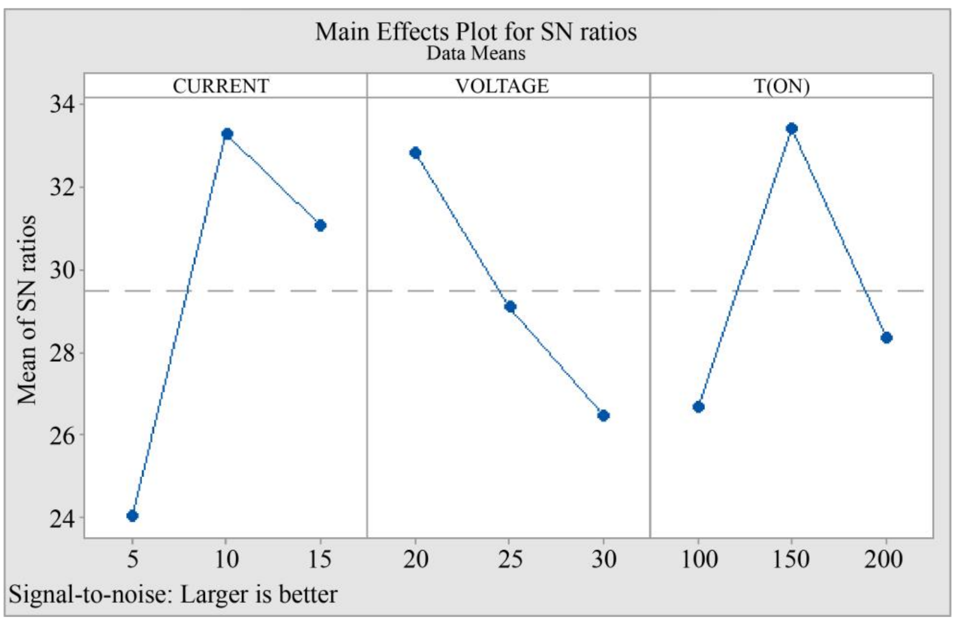


**Fig. 16 SN ratio plot for "MRR"**

**Table 14. Tabulation of Taguchi Analysis (Final Result obtained after the Taguchi Analysis of Design of Experiment for Aluminium -7075 hybrid MMC in tabulation format)**

| Current | Voltage | T(On) | Roughness Value | Mrr | Snra1 | Mean1 | Snra2 | Mean2 |
|---|---|---|---|---|---|---|---|---|
| 5 | 20 | 100 | 4.981 | 19.2814 | -13.9463 | 4.981 | 25.7028 | 19.2814 |
| 5 | 25 | 150 | 3.889 | 22.7651 | -11.7968 | 3.889 | 27.1454 | 22.7651 |
| 5 | 30 | 200 | 2.844 | 9.2399 | -9.0786 | 2.844 | 19.3133 | 9.2399 |
| 10 | 20 | 150 | 5.070 | 100.2635 | -14.1002 | 5.070 | 40.0229 | 100.2635 |
| 10 | 25 | 200 | 9.827 | 44.1234 | -19.8484 | 9.827 | 32.8934 | 44.1234 |
| 10 | 30 | 100 | 4.846 | 22.4399 | -13.7077 | 4.846 | 27.0204 | 22.4399 |
| 15 | 20 | 200 | 3.801 | 43.6332 | -11.5980 | 3.801 | 32.7963 | 43.6332 |
| 15 | 25 | 100 | 7.319 | 23.2825 | -17.2890 | 7.319 | 27.3406 | 23.2825 |
| 15 | 30 | 150 | 5.200 | 45.3114 | -14.3201 | 5.200 | 33.1241 | 45.3114 |

**Table 15. ANOVA Analysis Result OF "Ra" For Al-7075 Hybrid MMC**

| Roughness Value (Ra) | Results |
|---|---|
| Ra Versus Current | In Aluminium-7075 grade, the surface roughness is found to be maximum during the transition period of the machining when the current provided is 10ampere and gradually decreases when the current provided is 15ampere. During the beginning of the machining process, there is a steady increase in the roughness value when the current provided is 5ampere. |
| Ra Versus Voltage | In the Aluminium-7075 grade, the surface roughness is found to be maximum during the transition period of the machining when the voltage provided is 25 volts, and it is found to be minimum at 30 volts. |
| Ra Versus T(On) | In Aluminium-7075 grade, the surface roughness is found to be maximum during the end period of the machining when the T(on) provided is 200 microseconds and is found to be minimum at 150 microseconds. |

**Table 16. ANOVA Analysis Result of "MRR" for Al-7075 Hybrid MMC**

| Material Removal Rate (Mrr) | Results |
|---|---|
| Mrr Versus Current | In Aluminium-7075 grade, the maximum MRR rate in current is found to be 10ampere, and the lowest MRR rate in current is found to be 5ampere. |
| Mrr Versus Voltage | In Aluminium-7075 grade, the maximum MRR rate in voltage is found to be 20 volts, and the minimum MRR rate in voltage is found to be 30 volts. |
| MRR VERSUS T(On) | In Aluminium-7075 grade, the maximum MRR rate in T(on) is found to be 150microseconds and minimum MRR rate in T(on) is found to be 100microseconds |

**Table 17. ANOVA Result for Percentage Contribution of Factors for Al-7075 Hybrid MMC**

| Response Factors | Results |
|---|---|
| Surface Roughness | The highest contributing factor is found to be current, with a 38.30% value, which affects the surface roughness value. The contributing factors of voltage and T(on) are found to be 26.07% and 11.78%, respectively. |
| Material Removal Rate | The highest contributing factor is found to be current, with a 49.91% value, which affects the MRR. The contributing factors of voltage and T(on) are found to be 21.78% and 26.41%, respectively. |

*3.1.3. All Results Obtained From Taguchi Analysis For Design Of Experiment (Al-7075 Hybrid MMC)*

From the Taguchi Analysis of the design of the experiment, The optimum Surface Roughness value from the S/N criterion (smaller the better ) is found at Current= 5 ampere, Voltage= 30 volt and T(on)= 200.

Here, the S/N ratio is nearly equal to the predicted value of the Taguchi Analysis.

Predicted value for the S/N ratio is -9.5543

And at an optimum level, the S/N ratio is -9.0786

The optimum Material Removal Rate value from the S/N criterion (larger the better ) is found to be at Current= 15 ampere, Voltage= 20 volt and T(on)= 150.

Here, the S/N ratio is nearly equal to the predicted value of the Taguchi Analysis.

Predicted value for the S/N ratio is 40.6150.

At the optimum level, the S/N ratio is 40.0229.

All results obtained from the ANOVA analysis of parameters are given in Tables 15, 16 and 17.

## 4. Conclusion

The hybrid MMC (Al-6061 and Al-7075) specimen is prepared through a stir-casting process. The lathe machining operation is carried out to get the required dimensions of the fabricated hybrid MMC. A Universal Testing Machine finds the machined specimen's tensile strength and ultimate tensile strength. Then, the hardness number is calculated for the fabricated hybrid MMC using the Rockwell Hardness Testing machine. EDM machining operation is carried out for the machining analysis for both grades of fabricated hybrid MMC. The MRR is calculated for both the grades of hybrid MMC, and the surface roughness value is taken out using the surface roughness measuring instrument. Taguchi analysis is performed to calculate the optimum level for machining operations. The specific conclusions from the above study are presented below:

- The optimum Surface Roughness value from the S/N criterion (smaller the better ) is found to be at Current= 5 ampere, Voltage= 30 volt and T(on)= 200 for Al-6061 Hybrid MMC and the optimum Surface Roughness value for Al-7075 is found to be at Current= 5 ampere, Voltage= 30 volt and T(on)= 200.
- The S/N ratio is nearly equal to the predicted value of the Taguchi Analysis for Al-6061 Hybrid MMC, and its Predicted value for the S/N ratio is -15.1048, whereas at the optimum level, the S/N ratio is -14.6060.
- The S/N ratio is nearly equal to the predicted value of the Taguchi Analysis for Al-7075 Hybrid MMC, and its Predicted value for the S/N ratio is -9.5543, whereas at the optimum level, the S/N ratio is -9.0786.

- The optimum Material Removal Rate value from the S/N criterion (larger the better ) is found to be at Current= 15 ampere, Voltage= 20 volt and T(on)= 200 Al-6061 Hybrid MMC and the optimum Surface Roughness value for Al-7075 is found to be at Current= 15 ampere, Voltage= 20 volt and T(on)= 150.
- The S/N ratio is nearly equal to the predicted value of the Taguchi Analysis for Al-6061 Hybrid MMC. The predicted value for the S/N ratio is 33.1206, whereas at the optimum level, the S/N ratio is 33.3956.
- The S/N ratio is nearly equal to the predicted value of the Taguchi Analysis for Al-7075 Hybrid MMC, and its Predicted value for the S/N ratio is 40.6150, whereas at the optimum level, the S/N ratio is 40.0229.
- It has also been observed that Al-6061 Hybrid MMC has low tensile strength and yield strength compared to Al -7075 Hybrid MMC.
- From the Edm machining process, the MRR is found to be smoother in the case of Al-6061 Hybrid MMC than Al-7075 Hybrid MMC.
- Al-6061 Hybrid MMC has a higher Rockwell hardness number than the Al-7075Hybrid MMC. Due to the high hardness number, the ability to resist fracture decreases simultaneously.

ANOVA analysis determines the relative effectiveness of machining parameters with MRR and surface roughness and their percentage distribution factor.

## Environmental and Economic Impact

Thermosetting resin composites and thermoplastic composites are used in aircraft construction, reducing the plane's weight and producing low fuel consumption. Metal matrix composites demand in the global market is growing in the present future for manufacturing of automobile parts and aerospace industries due to light weights and longevity.

## Future Scope

The future work of the fabricated hybrid MMC can be done for the following cases:

- ECM may be carried out in order to investigate the machinability of these composites.
- The microstructural study of the newly fabricated AL-6061 and AL-7075 Hybrid Metal Matrix Composites can be conducted.
- To find out if any new metals are formed by adding boron carbides and silicon carbides by studying their internal properties and composition in detail.

## Funding Statement

The author bears all the research work, including the material's fabrication and the thesis's publication. The author has not financially taken any help from outer bodies or organizations.

## References

[1] K. Kalaiselvan, N. Murugan, and Siva Parameswaran, "Production and Characterization of AA6061–B4C Stir Cast Composite," *Materials and Design*, vol. 2, pp. 4004-4009, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[2] Fei Chen et al., "$TiB_2$ Reinforced Aluminum Based in Situ Composites Fabricated by Stir Casting," *Materials Science and Engineering*, vol. 625, pp. 357-368, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[3] B. Ashok Kumar, and N. Murugan, "Metallurgical and Mechanical Characterization of Stir Cast AA6061-T6–AINp Composite," *Materials and Design*, vol. 40, pp. 52-58, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[4] Hamid Reza Ezatpour et al., "Investigation of Microstructure and Mechanical Properties of Al6061-Nanocomposite Fabricated by Stir Casting," *Materials and Design*, vol. 55, pp. 921-928, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[5] N. Vinoth Babu, and T.V. Moorthy, "Synthesis and Characterization of Al7075/Sic Composite by Stir Casting," *Applied Mechanics and Materials*, vol. 592-594, pp. 760-764, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[6] K.V. Mahendra, and K. Radhakrishna, "Characterization of Stir Cast Al-Cu-(fly Ash + SiC) Hybrid Metal Matrix Composites," *Journal of Composite Materials*, vol. 44, no. 8, pp. 989-1005, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[7] R. Harichandran, and N. Selvakumar, "Effect of Nano/Micro B4C Particles on the Mechanical Properties of Aluminium Metal Matrix Composites Fabricated by Ultrasonic Cavitation-Assisted Solidification Process," *Archives of Civil and Mechanical Engineering*, vol. 16, no. 1, pp. 147-158, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[8] S.A. Sajjadi, H.R. Ezatpour, and M. Torabi Parizi, "Comparison of Microstructure and Mechanical Properties of A356 Aluminum Alloy/Al2O3 Composites Fabricated by Stir and Compo-Casting Processes," *Materials and Design*, vol. 34, pp. 106-111, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[9] Bijay Kumar Show et al., "Development of a Novel 6351 Al–($Al_4SiC_4$+SiC) Hybrid Composite with Enhanced Mechanical Properties," *Materials Science and Engineering: A*, vol. 579, pp. 136-149, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[10] R.M. Mohanty, K. Balasubramanian, and S.K. Seshadri, "Boron Carbide Reinforced Alumnium 1100 Matrix Composites: Fabrication and Properties," *Materials Science and Engineering A*, vol. 498, no. 1-2, pp. 42-52, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[11] V. Auradi, G.L. Rajesh, and S.A. Kori, "Preparation and Evaluation of Mechanical Properties of 6061Al–$B_4C_p$ Composites Produced via Two-Stage Melt Stirring," *Materials and Manufacturing Processes*, vol. 29, no. 2, pp. 194-200, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[12] A. Riaz Ahamed et al., "Drilling of Hybrid Al-5%SiC$_p$-5%B$_4$C$_p$ Metal Matrix Composites," *International Journal of Advanced Manufacturing Technology*, vol. 49, no. 9-12, pp. 871-877, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[13] Norliana Mohd Abbas, Darius G. Solomon, and Md. Fuad Bahari, "A Review on Current Research Trends in Electrical Discharge Machining (EDM)," *International Journal of Machine Tools and Manufacture*, vol. 47, no. 7-8, pp. 1214-1228, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[14] Rajesh Choudhary et al., "Performance and Surface Integrity of Nimonic75 Alloy Machined by Electrical Discharge Machining," *Materials Today: Proceedings*, vol. 2, no. 4-5, pp. 3481-3490, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[15] M.K. Das et al., "Optimization of Surface Roughness and MRR in EDM Using WPCA," *Procedia Engineering*, vol. 64, pp. 446–455, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[16] T. Muthuramalingam et al., "Monitoring and Fuzzy Control Approach for Efficient Electrical Discharge Machining Process," *Materials and Manufacturing Processes*, vol. 29, no. 3, pp. 281-286, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[17] S. Thirumalai Kumaran, and M. Uthayakumar, "Investigation on the Machining Studies of AA6351-SiC-B$_4$C Hybrid Metal Matrix Composites," *International Journal of Machining and Machinability of Materials*, vol. 15, no. 3/4, pp. 174-185, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[18] Aman Aggarwal et al., "Optimizing Power Consumption for CNC Turned Parts Using Response Surface Methodology And Taguchi's Technique - A Comparative Analysis," *Journal of Materials Processing Technology*, vol. 200, no. 1-3, pp. 373-384, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[19] Carmita Camposeco-Negrete, "Optimization of Cutting Parameters for Minimizing Energy Consumption in Turning of AISI 6061 T6 Using Taguchi Methodology and ANOVA," *Journal of Cleaner Production*, vol. 53, pp. 195-203, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[20] S. Gopalakannan, T. Senthilvelan, and S. Ranganathan, "Modeling and Optimization of EDM Process Parameters on Machining of Al 7075-B$_4$C MMC Using RSM," *Procedia Engineering*, vol. 38, pp. 685-690, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[21] S. Gopalakannan, and T. Senthilvelan, "A Parametric Study of Electrical Discharge Machining Process Parameters on Machining of Castal/B4C Metal Matrix Nano-Composites," *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol. 227, no. 7, pp. 993-1004, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[22] Srinivas Athreya, and Y.D. Venkatesh, "Application of Taguchi Method for Optimization of Process Parameters in Improving the Surface Roughness of Lathe Facing Operation," *International Refereed Journal of Engineering and Science*, vol. 1, no. 3, pp. 13-19, 2012. [Google Scholar]

[23] Bala Murugan Gopalsamy, Biswanath Mondal, and Sukamal Ghosh, "Taguchi Method and ANOVA : An Approach for Process Parameters Optimization of Hard Machining while Machining Hardened Steel," *Journal of Scientific and Industrial Research*, vol. 68, no. 8, pp. 686-695, 2009. [Google Scholar]