Analysis and Optimization of Abrasive water Jet Machining processes on the hybrid nano particle reinforced Aluminum alloy matrix composite material

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Abstract. The Nano hybrid particles reinforced aluminium based MMC has been prepared and characterized. The materials chosen for the fabrication of the composites include Aluminium Al6061 alloy(70%) as the base or matrix material in the composite reinforced with hybrid Nano materials as the particulate reinforcements (Cu-9%,Gr-9% and Al2O3-12%) were prepared by following the stir casting route. The developed material has been characterized and subjected to AWJM process. The input parameters were carefully chosen. The Experimental design was formulated for the orthogonal array of L30. Observations were made and the results were taken to the Design Expert software so as to do the optimization process. Reinforcing a hybrid mixture comprising of an alloy, a metal, a ceramic and allotropy of carbon in the matrix and analysing their properties are in itself unique and such works are scanty. The material thus fabricated showed few novel characteristics. The conduciveness of processing the material, aimed at providing the good quality surface and the ease of reducing the bulk material were investigated. Unique tool for optimization proposed by RSM “the Central composite Design” was put in to use in this work. Bearings, Bushes etc. known for their structural supports could be manufactured using this material exhibiting good machinability aspects.

Keywords. Hybrid nano composites, Design of experiments, ANOVA, RSM, Central composite Design, WP, AFR, TS,SOD

1. Introduction
The manufacturing sector relentlessly works to find a novel combination of materials that reduces the weight considerably, without compromising on their intended performance. The investigations so far carried out by erstwhile researchers have found material combinations that enhanced the performances
as well. The support structures of machineries, automobile spares and even in house hold appliances, the composites have taken a prominent role. Copper alloys are extensively used as a link device that supports a fixed member and a rotary member of machineries, owing to its load carrying capacity and wear resistance. The advent of materials under nano regime and becoming a particulate reinforcement in composite materials, show a positive role in related applications. Fretting wear is a phenomenon under heavy load conditions that can better be defeated with these MMCs comprising of nano reinforcements.

Hybridization of the composites, with the constituent reinforcements in form of a Ceramic, Carbon and another metal has been attracting the researchers for the past couple of previous decade. Characterizations pertaining to Wear, Corrosion and the Mechanical properties have been comprehensively done by the researchers like Michael Oluwatosin Bodunrin et al. [1]. T. Rajmohan et al. [2] utilized the power metallurgical path of developing the Aluminum based MMC and did an extensive work on the characterization. More over the present day research aspirants take the direction that leads to Aluminum matrix composites on a large scale. It has become obvious from the research reports, which strongly advocate, that the presence of particulate reinforcements increases the resistance of the work material towards Abrasion and wear at very high loads. Wear resistance at high loads increases with the increased volume of particulate reinforcements, ascertains Mohan Hossein et al. [3]. Copper alloys could expect a potential threat from Aluminum composites, as the better replacements in structural support systems, in the days to come. The difference in their melting point places Aluminum at the top, ahead of copper, when it comes to stir casting of Metal based hybrid composites.

Michael Oluwatosin Bodunrin et al. also reviewed the proportions and combinations of materials which are used as reinforcements, their impacts and roles were broadly debated alongside thereinforcements’ influences. A predominant portion was spent to analyse the factors lie in the reinforcements that influence the characteristics of the composites a whole. The techniques adopted in fabricating a composite material were also meticulously studied. The subtleties involved in the tribological characterization were stringently investigated. The investigators followed die compaction technique for the copper alloys, since copper exceeds the 1000°C range to turn in to a molten metal and the toxic inheritances of the copper alloys largely confine them to technique of powder metallurgy.

Ceramic reinforcements like Alumina, SiC and metal oxides were preferred widely. Present day applications find the presence of carbides of tungsten, silicon and even tantalum for supporting the structural rigidity and the thermal stability they provide to the structures is an additional feature. Hussain I Alalkawi et al. [4] developed aluminum based MMC using the stir casting technique with nano alumina taking the role of reinforcement enforcing a betterment in the mechanical properties. To improve the vigor of the hybrid composites, the numbers of reinforcements with appropriate compatibilities have been increased by the investigators. The allotropic form of the element carbon in Graphite plays a vital role in MMCs, where the lubricating property and wear resistances are the key. CNT in different forms have instigated the insight of the investigators in metallurgical and research laboratories. Yahya Altunpak et al. [5] investigated for, the ease with which an aluminium matrix hybrid composites could be drilled effectively, a better drilled surface at reasonable time. Suryanarayana et al. [6] made a deliberate and a detailed discussion on the Synthesizing methods on the variety of metal and ceramic matrix using the physical mode called as Ball milling techniques. Otherwise termed Mechanical alloying. Material compacting and sintering are the conventional techniques which aid the researchers. Thought the hindrances due to porosity are more, the researchers still lean towards stir casting techniques.

It has become essential for the investigators to understand the nature of the developed novel materials and to get them machined. Thyagarajan Rajmohan et al. [7] had preferred the central composite design for optimizing the drilling process Baradeswaran et al. [8] and Ke chu et al. [9] the researchers attempted to reinforce the carbon contents in form of Graphite and CNT in Al-Al₂O₃ and Cu-Cr composites respectively to study the wear resistive capability and the betterment achieved in the
mechanical properties of the composites, and their predictions came true through the positive results. The modern day investigators know the inevitability to choose an appropriate machining process and the parameters need to be optimized, says Bhaskar Chandra Kandpal et al. [10] and Conducted a detailed review analysis of the spark erosion on Al based MMC. Preetkanwal Singh Bains et al. [11], comprehended the methods of fabricating MMCs and did Optimizations have a maximized MRR without compromising on the surface quality. Gnanavel Babu et al. [12] initiated a refinement of the AJM process of a AA6061-B4C,HBN MMC, hybrid in nature, and reported it.

2. Experimental method

| S.No | Base Material | Reinforcents | % Composition | Technique adopted | Furnace & Temperature | Speed of the stirrer and duration |
|------|---------------|--------------|---------------|-------------------|------------------------|----------------------------------|
| 1    | Aluminum Alloy 6061 (70%) | Alumina Copper Graphite | 12 9 9 | Planetary Ball mill (Mechanical alloying at powder to ball ratio 10:1) 12 hrs of milling for individual elements and 8hrs for the hybrid mixture | 1000 °C Graphite Crucible Preheating 500°C | 250 rpm at 5 min |

Al, Al₂O₃, Cu, and Gr, were preheated at 500°C in a graphite crucible, for a uniform dispersion of reinforcements in to the aluminum alloy base [13]. Lighter Graphite particles have a buoyancy effect on the alumina particles. The materials were subjected to SEM analysis. The peaks values derived through XRD are similar and matches with the revelations by José Manuel Mendoza-Duarte et al. [14], to ascertain their entry in to the Nano scale regime. Table 1 provides the details of Material compositions and Techniques adopted. The plate like structures were cast with the dimensions of 100x100x10 in millimeters by adopting the Stir cast technique.

3. Mechanical Property of the material developed

| Mechanical Property | Hybrid Composite Developed | Stress Vs Strain Image obtained from Instron 5900 series | SEM Image |
|---------------------|----------------------------|--------------------------------------------------------|-----------|
| Vickers hardness, (MPa) | 431.4 | | |
| Yield strength(KN/MM²) | 67 | | |
| Ultimate Tensile strength(MPa) | 156 | | |
The tensile testing machine a capacity of 600kN was used to measure the ultimate tensile strength as per the ASTM standards. Gauge length = 60mm and Diameter of the gauge length zone= 12.5mm are the dimensions of the specimen prepared for the tests.

4. Machining
The Specification of the “Aqua cut” abrasive water jet machine that has been used for this work is shown in the Table 3.

| Specification of the Abrasive Water Jet Machining |
|--------------------------------------------------|
| X-Y cutting travel | Mm | 1575 x 1575 |
| Table Size | Mm | 2337 x 1752 |
| Material support slats | m/min | 102 x 2 |
| Max Traverse speed | m/min | 9 |
| Max Power | Hp | 30 |
| Delivery of Water | Litres/min | 3.2 |
| Max Pressure | Bar | 3800 |
| Repeatability | Mm | 0.05 |
| Orifice Diameter | Mm | 0.25 or lesser |
| Focusing Nozzle Size | Mm | 0.5 or lesser |

The input parameters and their levels are shown in Table V. Minitab software was used to develop the Experimental design to conduct the various experiments. Table IV gives the information pertaining to the experimental observations and the values of the output variables. Method of calculating the outcomes from the observations are given below [15].

\[
\text{MRR} = \text{Mean cutting speed} \times \text{Thickness of the material in mm} \times \text{Width of cut (mm)}
\]

\[
\text{MRR} = V_c \times t \times b \text{ mm}^3/\text{min} \tag{1}
\]

The MRR could be evaluated in Kg/min or in grams of weight, by measuring the weight before and after the machining and subsequently dividing it by the time to machine. The aforesaid formula provides the investigator the value of MRR in Volume. INSPEX, the measuring device with vision sensors was used to test the surface roughness [16] make were used to measure Kerf Width and surface quality respectively.

| Table 4. Input parameters and their levels with ranges |
|------------------------------------------------------|
| **Input parameters** | **Level 1** | **Level 2** | **Level 3** |
| Water cutting pressure in MPa | 300 | 325 | 350 |
| Traverse Speed in mm/min | 250 | 300 | 350 |
| Abrasive flow rate, gm/min | 300 | 350 | 400 |
| Standoff distance, mm | 2 | 4 | 6 |
Table 5. Experimental Observations

| STD | RUN | WATER CUTTING PRESSURE | TRAVERSE SPEED | ABRASIVE FLOW RATE | SOD (Stand Of Distance) | KERF WIDTH | SURFACE ROUGHNESS | MRR (Material Removal Rate) |
|-----|-----|-------------------------|----------------|-------------------|--------------------------|------------|-------------------|----------------------------|
|     |     | MPa | mm/min | grams/min | mm | mm | µm | mm³/min |
| 1   | 12  | 300.00 | 250.00 | 300.00 | 2.00 | 0.669 | 5.78 | 1672.5 |
| 2   | 19  | 350.00 | 250.00 | 300.00 | 2.00 | 0.668 | 5.64 | 1670 |
| 3   | 1   | 300.00 | 350.00 | 300.00 | 2.00 | 0.668 | 5.64 | 2338 |
| 4   | 2   | 350.00 | 350.00 | 300.00 | 2.00 | 0.71 | 5.98 | 2485 |
| 5   | 8   | 300.00 | 250.00 | 400.00 | 2.00 | 0.698 | 5.98 | 1745 |
| 6   | 15  | 350.00 | 250.00 | 400.00 | 2.00 | 0.657 | 5.703 | 1642.5 |
| 7   | 29  | 300.00 | 350.00 | 400.00 | 2.00 | 0.65 | 5.53 | 2275 |
| 8   | 14  | 350.00 | 350.00 | 400.00 | 2.00 | 0.656 | 5.569 | 2296 |
| 9   | 25  | 300.00 | 250.00 | 300.00 | 6.00 | 0.712 | 5.93 | 1780 |
| 10  | 24  | 350.00 | 250.00 | 300.00 | 6.00 | 0.695 | 5.85 | 1737.5 |
| 11  | 4   | 300.00 | 350.00 | 300.00 | 6.00 | 0.657 | 6.137 | 2299.5 |
| 12  | 6   | 350.00 | 350.00 | 300.00 | 6.00 | 0.666 | 6.055 | 2331 |
| 13  | 5   | 300.00 | 250.00 | 400.00 | 6.00 | 0.699 | 5.857 | 1747.5 |
| 14  | 18  | 350.00 | 250.00 | 400.00 | 6.00 | 0.712 | 5.93 | 1780 |
| 15  | 27  | 300.00 | 350.00 | 400.00 | 6.00 | 0.692 | 6.24 | 2422 |
| 16  | 22  | 350.00 | 350.00 | 400.00 | 6.00 | 0.678 | 6.198 | 2373 |
| 17  | 21  | 300.00 | 300.00 | 350.00 | 4.00 | 0.634 | 5.23 | 1902 |
| 18  | 7   | 350.00 | 300.00 | 350.00 | 4.00 | 0.67 | 5.377 | 2010 |
| 19  | 17  | 325.00 | 250.00 | 350.00 | 4.00 | 0.621 | 5.361 | 1552.5 |
| 20  | 28  | 325.00 | 350.00 | 350.00 | 4.00 | 0.598 | 4.99 | 2093 |
| 21  | 10  | 325.00 | 300.00 | 300.00 | 4.00 | 0.611 | 4.89 | 1833 |
| 22  | 26  | 325.00 | 300.00 | 400.00 | 4.00 | 0.621 | 5.639 | 1863 |
| 23  | 9   | 325.00 | 300.00 | 350.00 | 2.00 | 0.659 | 5.676 | 1977 |
| 24  | 13  | 325.00 | 300.00 | 350.00 | 6.00 | 0.721 | 6.07 | 2163 |
| 25  | 3   | 325.00 | 300.00 | 350.00 | 4.00 | 0.611 | 4.867 | 1833 |
| 26  | 11  | 325.00 | 300.00 | 350.00 | 4.00 | 0.611 | 4.89 | 1833 |
| 27  | 30  | 325.00 | 300.00 | 350.00 | 4.00 | 0.605 | 4.87 | 1815 |
5. Result and Discussion

Design Expert Software has been used to find out the relationship between the parametric combinations and their influences in the output variables. The relationships were obtained and shown in the form of graphs. The graphical representations give a concrete idea. The analysis of Variance have been done to ascertain the role and significance of certain input variables and they have been discussed in detail in this chapter [17]. The abbreviations used in this paper are: WP-Water Cutting Pressure, AFR- Abrasive flow rate, SOD- Stand Off Distance, TS-Traverse Speed.[18].

5.1. KERF WIDTH

Table 6. ANOVA for KERF width

| Source  | Sum of Squares | Df | Mean Square | F Value | p-value < Prob > F |
|---------|----------------|----|-------------|---------|--------------------|
| Model   | 0.037          | 14 | 2.662E-003  | 8.13    | 0.0001 Significant |
| A-WCP   | 6.050E-0051    | 1  | 6.050E-005  | 0.18    | 0.6734             |
| B-TS    | 1.352E-003     | 1  | 1.352E-003  | 4.13    | 0.0602             |
| C-AFR   | 2.722E-006     | 1  | 2.722E-006  | 8.317E-003 | 0.9285            |
| D-SOD   | 2.156E-003     | 1  | 2.156E-003  | 6.59    | 0.0215             |
| AB      | 4.951E-004     | 1  | 4.951E-004  | 1.51    | 0.2377             |
| AC      | 2.976E-004     | 1  | 2.976E-004  | 0.91    | 0.3555             |
| AD      | 1.406E-005     | 1  | 1.406E-005  | 0.043   | 0.8386             |
| BC      | 1.381E-004     | 1  | 1.381E-004  | 0.42    | 0.5259             |
| BD      | 8.556E-004     | 1  | 8.556E-004  | 2.61    | 0.1268             |
| CD      | 6.891E-004     | 1  | 6.891E-004  | 2.11    | 0.1674             |
| A²      | 1.749E-003     | 1  | 1.749E-003  | 0.3869  | 0.0354             |
| B²      | 7.069E-004     | 1  | 7.069E-004  | 2.16    | 0.1623             |
| C²      | 2.600E-004     | 1  | 2.600E-004  | 0.79    | 0.3869             |
| D²      | 0.011          | 0.011 | 32.40   | < 0.0001 |
| Residual| 4.910E-003     | 15 | 3.273E-004 |         |                    |
| Lack of Fit | 4.880E-004 | 10 | 4.880E-004 | 81.33 < 0.0001 | significant |
| Pure Error | 3.000E-005 | 5  | 6.000E-006 |         |                    |

The Model F-value is significant because the value of 8.13 justifies it and a 0.01% chance prevails for the F-Value" could occur to be larger due to noise. The model terms are significant due to Values of "Prob > F" goes below 0.005. In this case D, A2, D2 are significant model terms, which is being supported by the value of 0.1000.
5.1.1. Final Equation in Terms of Actual Factors

KERFWIDTH = +4.08085 - 0.027001*WATERCUTTINGRESSURE + 3.04838E-003*TRAVERSESPEED + 4.02394E-003*ABRASIVE FLOW RATE - 0.11743*STANDOFFDISTANCE + 4.45000E-006*WATER CUTTING PRESSURE*TRAVERSESPEED - 3.45000E-006*WATER CUTTING PRESSURE*ABRASIVE FLOW RATE - 1.87500E-005*WATER CUTTING PRESSURE*STAND OFF DISTANCE - 1.17500E-006*TRAVERSE ABRASIVEFLOWRATE - 7.31250E-005*TRAVERSESPEED*STANDOFFDISTANCE + 6.56250E-005*ABRASIVE FLOW RATE * STAND OFF DISTANCE + 4.15719E-005*WATER CUTTING PRESSURE 2 - 6.60702E-006*TRAVERSESPEED 2 - 4.00702E-006*ABRASIVEFLOWRATE 2 + 0.015996*STANDOFFDISTANCE 2

(2)

Figure 1. Normal Distribution Curve for KERF WIDTH

Figure 2. Water Cutting Pressure VS Traverse Speed for KERF WIDTH

The water cutting pressure and Traverse speed have no influence on the KERF WIDTH. The width becomes minimum at moderate pressure and traverse speed. The abrasive flow rate goes up with the pressure and water pressure. The higher speed and pressure erodes the material at a uniform rate and maintains a uniform width. Higher pressure and velocity provides the needed kinetic energy and the
thrust force to reduce the material a uniform measure. This is also due to the diameter of the jet which maintains a constant and a uniform cross sectional area. The turbulence of the jet erodes the material more at moderate traverse speed and water pressure where as the low pressure and speed reduces the required force to remove the material.

The distribution curve shown in Figure 1. shows the values lie along the mean line and Figure 2. shows the relation ship between WP and TS.

Higher the standoff distance and water pressure it is obvious that higher would be the width. The moderate standoff distances reduces the kerfwidth. Lower pressure and lower stand off distance also keeps the kerfwidth at a maximum. The pressure and kinetic energy plays an important role at higher input process variables whereas the potential energy takes its stake at lower values to maintain the width to be maximum. The moderate values at the middle level may be due to the deviation of the variables from the mean line as shown in the Normal plot. The Figure 3., Figure 4., and Figure 5. explains the role palyed by the parameters WP, AFR and SOD. The graphs clearly explain the parametric roles.
The combination of Abrasive flow rate at minimum Traverse speed gives a maximum kerf width. More the amount of abrasives that flow in and hit the work piece at lower transverse speeds give ample time for the abrasive materials to reduce the material and maintain the higher width of cut. The lower abrasive flow rates at lower traverse speeds fail to increase the kerf width since the volume of abrasive cutting fluid dips. The interactive effects of water pressure and Standoff distance play a significant role and influence the change in kerf width.

Figure 5. Traverse Speed VS Abrasive Flow Rate for KERF WIDTH

The higher standoff distance helps to have a greater width irrespective of traverse speed. The value of kerf width comes down with the decrease in standoff distance. The Figure 6 and the Figure 7 explain the SOD Vs TS and SOD Vs AFR respectively pertaining to Kerf width.

Figure 6. Traverse Speed VS Standoff Distance for KERF WIDTH
5.2. SURFACE ROUGHNESS

Table 7. ANOVA for Surface roughness

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F |
|--------|----------------|----|-------------|---------|-----------------|
| Model  | 5.51           | 14 | 0.39        | 6.91    | 0.0003 Significant |
| A-WCP  | 2.689E-005     | 1  | 2.689E-005  | 4.720E-004 | 0.9830 |
| B-TS   | 5.270E-003     | 1  | 5.270E-003  | 0.093   | 0.7652 |
| C-AFR  | 0.031          | 1  | 0.031       | 0.54    | 0.4739 |
| D-SOD  | 0.43           | 1  | 0.43        | 7.48    | 0.0154 |
| AB     | 0.029          | 1  | 0.029       | 0.51    | 0.4879 |
| AC     | 3.752E-003     | 1  | 3.752E-003  | 0.066   | 0.8010 |
| AD     | 5.406E-004     | 1  | 5.406E-004  | 9.488E-003 | 0.9237 |
| BC     | 0.019          | 0.019 | 0.33 | 0.5766 |
| BD     | 0.13           | 1  | 0.13        | 2.30    | 0.1504 |
| CD     | 0.016          | 1  | 0.016       | 0.29    | 0.6003 |
| A²     | 0.034          | 1  | 0.034       | 0.60    | 0.4491 |
| B²     | 4.215E-004     | 1  | 7.398E-003  | 0.9326 |
| C²     | 0.015          | 1  | 0.015       | 0.26    | 0.6146 |
| D²     | 1.21           | 1  | 21.32       | 0.0003 |
| Residual | 0.85        | 15 | 0.057 |
| Lack of Fit | 0.85 | 10 | 308.94 | < 0.0001 Significant |
| Pure Error | 1.381E-003 | 5  | 2.762E-004 |
| Cor Total | 6.37       | 29 |

Figure 7. Abrasive Flow Rate VS Standoff Distance for KERF WIDTH
The Model F-value is significant because the value of 6.91 justifies it and a 0.03% chance prevails for the F-Value" could occur to be larger due to noise. The model terms are significant due to Values of "Prob > F" goes below 0.005. In this case D, D² are significant model terms, which is being supported by the value of 0.1000.

5.2.1. Final Equation in Terms of Actual factors
SURFACE ROUGHNESS =+31.70811 - 0.12534* WATER CUTTING PRESSURE - 6.47923E-003* TRAVERSE SPEED - 0.013731 * ABRASIVE FLOW RATE - 1.63789* STAND OFF DISTANCE + 3.39500E-005 * WATER CUTTING PRESSURE * TRAVERSE SPEED - 1.22500E-005 * WATER CUTTING PRESSURE * ABRASIVE FLOW RATE - 1.16250E-004 * WATER CUTTING PRESSURE * STAND OFF DISTANCE - 1.36250E-005 * TRAVERSE SPEED * STAND OFF DISTANCE - 5.10175E-006 * TRAVERSE SPEED² + 3.04982E-005* ABRASIVE FLOW RATE² + 0.17119* STAND OFF DISTANCE²

\[ \text{SURFACE ROUGHNESS} = +31.70811 - 0.12534\times \text{WATER CUTTING PRESSURE} - 6.47923\times 10^{-3}\times \text{TRAVERSE SPEED} - 0.013731 \times \text{ABRASIVE FLOW RATE} - 1.63789 \times \text{STAND OFF DISTANCE} + 3.39500\times 10^{-5} \times \text{WATER CUTTING PRESSURE} \times \text{TRAVERSE SPEED} - 1.22500\times 10^{-5} \times \text{WATER CUTTING PRESSURE} \times \text{ABRASIVE FLOW RATE} - 1.16250\times 10^{-04} \times \text{WATER CUTTING PRESSURE} \times \text{STAND OFF DISTANCE} - 1.36250\times 10^{-05} \times \text{TRAVERSE SPEED} \times \text{STAND OFF DISTANCE} - 5.10175\times 10^{-06} \times \text{TRAVERSE SPEED}^2 + 3.04982\times 10^{-05} \times \text{ABRASIVE FLOW RATE}^2 + 0.17119 \times \text{STAND OFF DISTANCE}^2 \] (3)

Figure 8. Normal Distribution Curve for Surface Roughness

Figure 9. Water Cutting Pressure VS Traverse Speed for Surface Roughness
The water cutting pressure and Traverse speed maintains the value of surface roughness constant and uniform. The roughness value takes an edge upwards at higher values of speed and pressure. The combinatorial effects of traverse speed and water pressure works in tandem to make the interaction with the surface at a uniform fashion. The pressure and speed joins together to maintain a very good surface quality. The abrasive particles erode the workpiece at a proportional variation in the joint effort of kinetic and pressure energies.

The abrasive flow rate and water pressure also provide a proportional variation with respect to surface roughness. The intensity of abrasive particles at a proportionately intensified water pressure maintains a smooth exit of materials from the bulk so as to ensure a better and uniform surface finish. This parametric combination has no distinctive difference or variation in achieving the surface finish. The sharp edges of the abrasive particles at a given pressure removes the material that ascertains the waviness to be uniform and stable.

Figure 8 gives the normal plot where the values of the control variables lie within the predictable lines and follow the mean line. Figure 13, Figure 14 and Figure 15 explain the interactions between them as well as the role played by the individual parameter in establishing a better surface roughness.

The water cutting pressure and standoff distances have an explicit effects on surface roughness. Higher stand off distances increases the surface roughness at higher pressures. The thudding force with which the abrasive particles penetrate the surface and weakens the cohesive forces that bind the base material and the reinforcements. The imbalance created by the hard abrasive particles at higher pressure disrupts the uniformity of the materials layer at the surface and affects the surface. The lower pressure and stand off distance lag the needed impact force of penetration. The surface energy that helps to deplete the outer layer goes down at the lower stand off distance and during the lower water cutting pressures.
Traverse speeds and abrasive flow rates jointly make no appreciable impact in the surface roughness. Whatever be their values they maintain a uniform surface finish. The traverse speed pushes the water jet along with it at almost the similar and equivalent flow rate and the surface roughness remains unaltered. The variation adopted by these parameters simultaneous have no telling impact on the surface quality.

The effects of traverse speed and standoff distance also give us an interesting understanding, more the stand off distance and traverse speed the surface roughness shoots up. The propellent abrasive jet from the nozzle if takes longer distances to reach the target material and at the same time if the table traverse is also faster, ther is a greater possibility of material scatter along the surface. There would be a lack of cutting force developed along the surfaces, the speed with which the nozzle or the table is moved, if they fail to take up the impact then the uniformity of removal comes down and it would have a telling impact on the surface quality.
The aforesaid effect is quite similar to the relationship between the traverse speed and standoff distance. The surface roughness values are greater at higher values of these two parameters. More the rate of abrasive particles from a greater height, the volume of materials with needed hardness falling on the work piece material is more. The no of pointed edges of the particles try to remove or damage the already machined surface. The frequency of the abrasive particle coming in to contact with the surface also increases abruptly there by affecting the surface quality. In a way these two combinations may have a reasonable impact in material removal rate as well.
5.3. MATERIAL REMOVAL RATE

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F |
|--------|----------------|----|-------------|---------|----------------|
| Model  | 2.048E+006     | 14 | 1.463E+005  | 43.81   | <0.0001 Significant |
| A-WCP  | 114.01         | 1  | 114.01      | 0.34    | 0.5670 |
| B-TS   | 1.733E+006     | 1  | 0.35        | 1.04E-004 | 0.9920 |
| C-ABR  | 0.35           | 1  | 0.35        | 1.04E-004 | 0.9920 |
| D-SOD  | 15753.13       | 1  | 15753.13    | 4.72    | 0.0463 |
| AB     | 4405.64        | 1  | 4405.64     | 1.32    | 0.2687 |
| AC     | 3349.52        | 1  | 3349.52     | 1.00    | 0.3324 |
| AD     | 511.89         | 1  | 511.89      | 0.15    | 0.7009 |
| BC     | 1269.14        | 1  | 1269.14     | 0.38    | 0.5468 |
| BD     | 5023.27        | 1  | 5023.27     | 1.50    | 0.2389 |
| CD     | 9096.39        | 1  | 9096.39     | 2.72    | 0.1196 |
| A²     | 15923.04       | 1  | 15923.04    | 4.77    | 0.0453 |
| B²     | 7796.30        | 1  | 7796.30     | 2.33    | 0.1473 |
| C²     | 2270.86        | 1  | 2270.86     | 0.68    | 0.4225 |
| D²     | 95904.40       | 1  | 95904.40    | 28.72   | <0.0001 Significant |
| Residual | 50083.82    | 15 | 3338.92     |         |         |
| Lack of Fit | 49813.82 | 10 | 4981.3892.25 | <0.0001 Significant |
| Pure error | 270.00     | 5  | 54.00       |         |         |
| Cor Total | 2.098E+006  | 29 |             |         |         |

The Model F-value is significant because the value of 43.81 justifies it and a 0.01% chance prevails for the F-Value" could occur to be larger due to noise. The model terms are significant due to values of "Prob > F" goes below 0.005. In this case B, D, A², D² are significant model terms, which is being supported by the value of 0.1000.

5.3.1. Final Equation in Terms of Actual Factor

MATERIAL REMOVAL RATE =+10000.86349-80.69039 * WATER CUTTING PRESSURE+17.01207 * TRAVERSE SPEED+12.16357 * ABRASIVE FLOW RATE-363.52906* STAND OFF DISTANCE+0.013275 * WATER CUTTING PRESSURE* TRAVERSE SPEED+0.011575 * WATER CUTTING PRESSURE * ABRASIVE FLOW RATE+0.11312 * WATER CUTTING PRESSURE * STAND OFF DISTANCE-3.56250E-003* TRAVERSE SPEED * ABRASIVE FLOW RATE-0.17719 * TRAVERSE SPEED * STAND OFF DISTANCE+0.12543 * WATER CUTTING PRESSURE+0.021942 * TRAVERSE SPEED-0.01842* ABRASIVE FLOW RATE+0.48.09868*STAND OFF DISTANCE² (4)
From the diagram it is clear that the higher cutting pressure and higher traverse speed removes material in large quantities. The pressure energy removes the material, the abrasive particles with a greater pressure hits the material’s surface they disturb the surface tension prevails in the materials. The more the disruption of the surface with pressurized fluid carrying the abrasive particles, the more material would be dislodged from the surface and ultimate the MRR takes a steep ride. The phenomenon mentioned above is vice-versa at the lower value combinations of the control parameters.
The water cutting pressure and abrasive flow rate if increases the material removal rate would also increase, this combination is effective even at the lower values of these control parameters. At higher values the pressurized abrasive slurry removes more amount of material, the high pressure and discharge of cutting particles ease the material reduction and increases the volume of material removal. Where as even at lower dischare and at lower pressure, the MRR is more since the abrasives keeps with it the inherent forces and aids the process of material removal.

![Figure 17. Water Cutting Pressure VS Abrasive Flow Rate for Material Removal Rate](image1)

![Figure 18. Water Cutting pressure VS Stand off Distance for Material Removal Rate](image2)

The standoff distance and pressure removes the material at a faster rate irrespective of their levels of performance. The reason for the high material removal at the higher values is a valid guess of any machinists, whereas even at lower values the MRR is high as well. The lower pressure and low standoff distance would give a better MRR only when the traverse speed is low. At lower traverse speeds, there is a more than sufficient time for the cutting material to disrupt the workpiece material. Lower stand off distances moreover require a higher pressure to remove the material, since the
quantity of abrasives present in the abrasive water jet would be more and cohesive so as to create an impact. If the abrasive slurry falls from greater heights the cohesiveness loosens up and the impact would be not of a consequential one.

Figure 15 shows the deviations of the process variables from the mean line whereas the Figure 16, Figure 17, Figure 18 and Figure 19 shows the role WP, TS, AFR and SOD in the pursuit of a better MRR.

The relationship with the Traverse speed and Abrasive flow rate has similar consequences to traverse speed and cutting pressure. The jet with high discharge abrasive slurry acts like a solid cutting tool; if it is traversed across the material then the resulting material removal would be high. The velocity of the table or the nozzle and discharge creates a greater rate of wear and erosion along the edges of the work piece there by provides a higher MRR. At lower speed and lower abrasive flow rate the MRR becomes low because there is an interaction with other parameters like low water pressure and lower standoff distance.

The traverse speed and standoff distance increases the MRR with their respective incremental values. Because of the virtual position of the nozzle, the energy would be higher and at higher traverse
speeds if the abrasive slurry impacts the workpiece, it creates the phenomenon quite similar to that of cutting the workpieces with a sharp edged tool. The high velocity jet with loads of energy impinges on the material traversing with substantial velocity would provide greater MRR.

The increased abrasive flow rate and higher stand off distance increase the MRR. If the much energized abrasive material in sufficient volume falls over the workpiece material for a period of time, then it creates a much needed disruption and dislodges the material in higher volumes, by weakening up the bonds already formed within the bulk material.

![Figure 21. Abrasive Flow Rate VS Stand off Distance for Material Removal Rate](image)

6. CONCLUSION
The hybrid material made of Aluminium Al6061 alloy (70%) as the base or matrix material in the composite reinforced with hybrid nano materials as the particulate reinforcements (Cu-9%,Gr-9% and Al2O3-12%) were prepared by following the stir casting route, sidelong the rule of mix. Good mechanical characteristics and resistance to the adverse rubbing consequence are part of material cast as MMC. Central composite design of RSM comprehends the effects and impacts of control parameters meticulously over the machining process. The interaction between individual process parameters and their combinatorial effects have been extensively scrutinized and put in a nutshell in this report. Lower the control variables viz., standoff distance, Abrasive flow rate, Traverse speed and water pressure, better is the surface quality. The impact created by the lower process control variable over the surface roughness is appreciable. Higher the input variables viz., traverse speed, water pressure, standoff distance and Abrasive flow rate, higher is the Material Removal Rate.

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