Parametric optimization and abrasive water jet drilling on bronze metal matrix composite

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Abstract. In recent scenario, the Metal Matrix Composites (MMC) has been an essential role in all sectors such as automotive, marine, aircraft, agriculture and nuclear power plants. The MMC has commendable material behaviors. The better material characteristics have been achieved after conversion metals to MMC through the addition of reinforcements. Due to improved corrosion resistance and strength of the bronze metal matrix was considered for the present experimental work. It was formulated through stir casting technique. The machinability characteristics were analyzed through Abrasive Water Jet Machining (AWJM) process. The responses such as the Material Removal Rate (MRR) and Surface Roughness (SR) were evaluated based on its input factors. Taguchi optimization, contour plot and variance test were also reported.

1. Introduction
In recent days, the demand for MMC in established applications under the corrosive environment has increased [1]. MMCs have a much lower weight, higher strength and stiffness and are more resistant to corrosion and wear [2]. Normally, bronze is harder than copper and more fusible. Hence, easier to cast and it’s to be converted any desired shape. It has been more resistant to corrosion. Bronze and its alloys have been used as pump plungers, valves, gears, coins, ship propellers and turbine blades. The abrasive water jet drilling experiment was conducted on brass, aluminium and steel. The thickness of the plate and its effect compared with weld time [3]. The taper angles and material removal rates of drilled holes were analyzed in polymers [4]. The surface roughness of the holes and optimization was analyzed in Inconel alloy [5]. Taguchi L9 orthogonal array was used to run the experiments and
optimize the factors [6]. The abrasive flow rate and standoff distance affected the machining surface of Inconel 718 alloy [7-8]. The performance analysis and factors effects were studied in abrasive water jet machining of titanium alloy [9]. The recent developments of AWJM process and its characteristics were studied [10]. The microstructure and defects of machining of aluminium MMC using AWJM process [11]. The water pressure was the dominant factor on MRR in AWJM of duplex brass [12]. The surface quality was improved during the abrasive water jet machining of hybrid carbon composites [13]. Parametric effects of AWJM with zirconium carbide and boron carbide reinforced molybdenum MMC were studied [14]. Many studies focused at the Taguchi technique with SN ratio and variance analysis to determine optimum conditions [15-36].

The present experimental work was dealt with the parametric optimization and abrasive water jet drilling on bronze metal matrix. The proposed investigation was to maximize the material removal rate and minimize surface roughness.

2. Experimental methods

2.1. Fabrication of MMC

The workpiece of bronze MMC is produced by stir casting method. The stir casting process has been considered due to its simplicity, flexibility, homogenous dispersion of the particles and mass production at low cost. The matrix material has been placed in a graphite crucible and it has been heated in a furnace at different temperature level (900˚C to 1200˚C). The reinforcement of SiC particles (size 50 µm) has been preheated at 1100˚C for one hour before added into the metal matrix. The preheated SiC particles have been added in the molten metal. The molten slurry was intentionally stirred about 750 rpm with different holding time (15, 30 and 40 minutes). The stirrer has been applied until to achieve the sufficient homogenous mixture. Simultaneously, argon gas has been supplied to avoid oxide layer formation. The molten metal has been poured into the mold cavity and then permit to solidification. The desired shape and size (100 x 50 x 10 mm) was converted from a solid piece. The composite fabricating setup through stir casting was revealed in Figure 1.

![Figure 1. Schematic of stir casting set up for fabricating composite](image)

The bronze MMC has copper (71.03%), zinc (12.36%), tin (6.91%), nickel (7.26%) and silicon carbide (2.44%). It has better substance properties such as hardness, elongation, tensile and impact strength and it was exposed in Table 1.
Table 1. Material properties of the bronze metal matrix

| S.No. | Properties                | Results    |
|-------|---------------------------|------------|
| 1     | Hardness                  | 355 BHN    |
| 2     | Tensile strength          | 570 MPa    |
| 3     | Impact strength           | 13 J       |
| 4     | Percentage of elongation  | 10 %       |

2.2. Experimental results and discussion
The stir casted bronze MMC is machined by unconventional machining of AWJM process. The responses such as MRR and SR were recorded through the change of water pressure, abrasive flow rate and traverse speed. The holes of 8 mm diameters have been performed on bronze plate. The surface roughness is measured through surface roughness tester (Talysurf SJ–201). The parameter levels have been shown in Table 2.

Table 2. Level of control parameters

| Levels | Water pressure (bar) | Traverse speed (mm/min) | Abrasive flow rate (gm/mm) |
|--------|----------------------|-------------------------|---------------------------|
| 1      | 3000                 | 30                      | 75                        |
| 2      | 3500                 | 60                      | 150                       |
| 3      | 4000                 | 90                      | 225                       |

2.3. Taguchi parametric optimization
The responses such as MRR and SR of the holes have been measured for each experiment and recorded in Table 3. Taguchi approach has been used for determining the optimal parametric combinations to achieve the maximum material removal rate and minimum surface roughness. The desired quality of the products depended on the design of experiments. The execution of system design and parametric design has been performed effectively using this method.

Table 3. Level of control parameters

| S.No. | A: Water pressure | B: Traverse speed | C: Abrasive flow rate | MRR (gm/min) | SR (µm)  |
|-------|-------------------|-------------------|-----------------------|--------------|----------|
| 1     | 1300              | 25                | 80                    | 8.32         | 3.41     |
| 2     | 1300              | 50                | 160                   | 6.45         | 2.65     |
| 3     | 1300              | 75                | 240                   | 12.43        | 1.99     |
| 4     | 2300              | 25                | 160                   | 11.67        | 4.32     |
| 5     | 2300              | 50                | 240                   | 14.68        | 5.21     |
| 6     | 2300              | 75                | 80                    | 9.92         | 3.68     |
| 7     | 3300              | 25                | 240                   | 16.46        | 2.33     |
| 8     | 3300              | 50                | 80                    | 13.79        | 1.56     |
| 9     | 3300              | 75                | 160                   | 20.24        | 1.24     |

2.4. Signal to noise (S/N) ratio analysis for MRR
The experiments have been carried out based on the orthogonal array which was able to reduce the number of trails. All experimental results have been transformed and evaluated through the signal to noise ratio. It was used to found the variations of the performance for desired values. The performance of the responses is related to the S/N ratio. Mean of S/N ratio has been shown in Table 4. From the SN
ratio analysis, the water pressure is the prime factor to affect MRR and it is ensured by the delta rank value.

Table 4. Mean of S/N ratio for MRR

| Level | Water pressure (bar) | Transverse speed (mm/min) | Abrasive flow rate (gm/mm) |
|-------|----------------------|---------------------------|---------------------------|
| 1     | 8.897                | 11.297                    | 9.68                      |
| 2     | 10.45                | 9.643                     | 11.34                     |
| 3     | 12.753               | 11.19                     | 11.08                     |
| Delta | 3.857                | 1.623                     | 1.66                      |
| Rank  | 1                    | 2                         | 3                         |

Figure 2 shows that the major effects and their difference between stages of the factors for material removal rate. To achieve MRR, larger the better criterion was preferred. Therefore the greatest possible level of parameter A3 B1 C2 was chosen from the graph. The optimal values for MRR were obtained at a water pressure of 4000 bar, Traverse speed of 30 mm/min and abrasive flow rate of 150 gm/mm. Based on variance analysis the most powerful and involvement parameter has been found. Table 5 shows that variance results for MRR. From the table, water pressure is the leading factor which affects the responses followed by transverse speed.

Table 5. Variance analysis for MRR

| Source            | DF | Adj SS | Adj MS | F- value | P- value |
|-------------------|----|--------|--------|----------|----------|
| Water pressure    | 2  | 22.9   | 11.3   | 10.72    | 0.085    |
| Transverse speed  | 2  | 5.03   | 2.51   | 2.39     | 0.30     |
| Abrasive flow rate| 2  | 4.78   | 2.39   | 2.27     | 0.31     |
| Error             | 2  | 2.11   | 1.05   |          |          |
| Total             | 8  | 34.52  |        |          |          |

S= 3.024; R-sq = 83.9%; R-sq (adj) = 85.7%
The interaction plot for MRR is shown in Figure 3. The interaction between input parameters and the output parameter has been observed from the given figure. It is perceived that water pressure plays an important for change as the material removal rate. The interaction of water pressure and transverse speed shows that the increase in water pressure increases the MRR irrespective of transverse speed. The interaction of Transverse speed and flow rate shows that the increase in water pressure increases the MRR.

![Interaction Plot for MRR](image)

**Figure 3. Interaction plot for MRR**

2.5. *Signal to noise (S/N) ratio analysis for SR*

For the experimental work, the minimum amount of surface roughness has been considered for drilling of the bronze metal matrix. Mean of S/N ratio has been shown in Table 6. Based on minimum surface roughness, lower the better criterion has been considered.

| Level | Water pressure (bar) | Transverse speed (mm/min) | Abrasive flow rate (gm/mm) |
|-------|----------------------|----------------------------|-----------------------------|
| 1     | 2.683                | 3.353                      | 2.883                       |
| 2     | 4.403                | 3.14                       | 2.737                       |
| 3     | 1.71                 | 2.303                      | 3.177                       |
| Delta | 2.693                | 1.050                      | 0.44                        |
| Rank  | 1                    | 2                          | 3                           |

The optimal level of parameter A2 B1 C3 has been preferred from the graph which was shown in Figure 4. The optimal values for SR are water pressure is 2300 bar, Traverse speed is 25 mm/min and the abrasive flow rate is 240 gm/mm. Table 7 shows that variance analysis results for SR. From the tale, water pressure is the foremost factor which it affects the surface roughness.
Figure 4. S/N ratio graph for SR

Table 7. ANOVA table for the SR

| Source                | DF | Adj SS  | Adj MS  | F– value | P– value |
|-----------------------|----|---------|---------|----------|----------|
| Water pressure        | 2  | 11.1598 | 5.5799  | 16.67    | 0.057    |
| Transverse speed      | 2  | 1.848   | 0.924   | 2.76     | 0.266    |
| Abrasive flow rate    | 2  | 0.3012  | 0.1506  | 0.45     | 0.690    |
| Error                 | 2  | 0.6697  | 0.3347  |          |          |
| Total                 | 8  | 13.9784 |         |          |          |

S = 0.568; R-sq = 94.9% ; R-sq (adj) = 87.7%

The interaction plot for SR is shown in Figure 5. The changes in response, such as SR have been noticed from the interaction graph drawn between input parameters and the output parameter. It is clearly noted that water pressure plays a vital role for the variation of surface roughness.

Figure 5. Interaction plot for SR
2.6. Contour plot analysis for MRR and SR
The contour plot analysis for water pressure and traverse speed is given in Figure 6. The maximum amount of MRR is achieved at higher values of water pressure and traverse speed. The contour plot analysis of water pressure and the abrasive flow rate is shown in Figure 7. The higher amount of MRR is obtained when a higher value of water pressure. The contour plot analysis of traverse speed and abrasive flow rate is shown in Figure 8. The higher amount of MRR is achieved at higher values of water pressure and traverse speed. The contour plot analysis for water pressure and traverse speed is given in Figure 6. The maximum amount of MRR is obtained at 70 mm/min and 125 to 200 gm/min. The contour plot analysis of traverse speed and the abrasive flow rate for SR is shown in Figure 9. From this graph, the minimum amount of surface finish is obtained at a higher and lower level of water pressure and traverse speed. The contour plot analysis of traverse speed and the abrasive flow rate for SR is shown in Figure 10. The contour plot analysis of traverse speed and abrasive flow rate for SR is shown in Figure 11. From this graph, the minimum amount of surface finish mainly depends on the traverse speed.

![Figure 6. Contour plot analysis of water pressure versus traverse speed](image1)

![Figure 7. Contour plot analysis of water pressure versus abrasive flow rate](image2)
Figure 8. Contour plot analysis of traverse speed versus abrasive flow rate

Figure 9. Contour plot analysis of water pressure versus traverse speed for SR

Figure 10. Contour plot analysis of water pressure versus abrasive flow rate for SR
Figure 11. Contour plot analysis of traverse speed versus abrasive flow rate for SR

3. Conclusions
The following conclusions are drawn from the above experimental study:

- The bronze metal matrix is fabricated through stir casting method. The substance properties of fabricated composite have been measured.
- The bronze metal matrix composite is machined through abrasive water jet machining process.
- The optimal parameters have been found using the Taguchi method. The optimal of MRR was achieved at a water pressure of 4000 bar, Traverse speed of 30 mm/min and abrasive flow rate of 150 gm/mm.
- The optimal values of SR are water pressure of 2300 bar, Traverse speed of 25 mm/min and abrasive flow rate of 240 gm/mm.
- From the variance test, water pressure is the most dominant parameter to affect the MRR and SR.

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Acknowledgments
The authors thank the Department of Mechanical Engineering, Anna University, Regional Campus Madurai, Madurai, Tamil Nadu, India for their continuous encouragement to carry out this research work.