# Effect of the B4C Reinforcement Ratio on Surface Roughness of Al6061 Based Metal Matrix Composite in Wire-EDM Machining

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*Abstract*—**This study investigates the machining properties of Al6061 reinforced with boron carbide ($B_4C$) and the effect of cutting parameters on surface roughness in wire electrical discharge machining of (WEDM). Four Al 6061 metal matrix composites reinforced with 5 wt.%, 10 wt.%, 15 wt.%, and 20 wt.% $B_4C$ were fabricated by powder metallurgy. Influence of the $B_4C$ reinforcement particles on surface roughness were studied during the WEDM. Experiments were conducted based on Taguchi $L_{18}$ ($2^1$ x $3^2$) with a mixed orthogonal array and the optimal machining parameters were investigated for the surface finish. The machining parameters were analyzed by using main effect graphs and analysis of variance (ANOVA). The results showed that the reinforcement particles were uniformly dispersed in matrix structure and the surface quality of machined specimens were improved with increasing the weight fraction of the $B_4C$ reinforcement. The best surface roughness values were measured at lower peak current (IP) and surface quality of the machined part was decreased with increasing peak current.**

***Keywords-Al 6061; B4C reinforcement; metal matrix composites; WEDM; surface roughness***

## I. INTRODUCTION

Aluminum and aluminum-based metal matrix composites (MMCs) have been studied by numerous researchers in recent years, parallel to the increasing demands to materials with lower weight in combination with higher mechanical properties such as wear resistance, hardness, impact toughness and ballistic resistance. Because of these superior properties, MMCs have become attractive in engineering applications such as armor, automotive industry, aerospace, sports equipment and electronic packaging. However, the machinability of MMCs is poor because of the hard abrasive-reinforcement particles lead to severe tool wear. Researchers were reported lower cutting tool life and higher cutting force in conventional machining of MMCs due to the high hardness and abrasive wear properties of the MMCs [1];[2];[3]. Therefore, several researchers were investigated wire electrical machining process (WEDM) of MMCs. WEDM is an electro thermal manufacturing process that allows metal to be cut using heat from electric sparks with a thin single wire metal in deionized water used for electrical conduction. Because of the unique properties of the process, WEDM can easily machine difficult-to-cut-electrically conductive materials independently of their hardness [3-6]. Fard et al.[3] performed an experimental investigation on dry WEDM process of Al-SiC MMCs and investigated the effect of the machining parameters on surface roughness. Experimental results showed that the oxygen gas and brass wire exhibited the superior cutting velocity and pulse on time and discharge current were the most effective machining parameter. Sharma et al.[7] developed an Al6063 based $ZrSiO_4$ reinforced composite materials and studied the machinability of the WEDM process. They investigated the influence of the machining parameters such as pulse on time, pulse off time, peak current and servo voltage on cutting rate. They found that the cutting rate increased with increasing the pulse on time and peak current. Patil et al.[8] studied the effect of the volume fraction of SiC reinforcement and wire electrode material on WEDM machining performance of A356/SiC composite materials. The authors reported that the volume fraction of reinforcement was the most effective parameter on cutting rate and pulse on time. The electrode material has the least influence on the machining process and surface roughness was increased with the coated wire. Lialo et al. [9] performed a study to achieve a fine surface quality in WEDM process with the Taguchi quality design. After analyzing the influence of each relevant variable on surface roughness using ANOVA, correct machining values were determined and a fine surface quality was achieved. Surya et al. [10] developed a prediction model using artificial neural network in Wire EDM of Al 7075 based composite and investigated machined surface quality, material removal rate (MMR) and minimum dimensional error. They stated that the estimated and experimental results were significantly coherent. Surface quality, cutting width, wire breakage behavior and material removal rate (MRR) were examined by Yan et al. [11] during the Wire EDM of $Al6061/Al_2O_3$ composites. The test result revealed that volume fraction of the $Al_2O_3$ powder has the most effective parameter on the

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surface roughness, MMR and kerf. They suggested that higher wire speed and flushing rate with the combination of very low wire tension must be used to prevent wire breakage. Motorcu et al. [12] performed an experimental study on the surface roughness and MRR in wire EDM of Al/$B_4C$/Gr hybrid MMCs using different pulse-on time, pulse-off time and wire speed variables. The authors reported that the most significant variable on surface finish and MRR was the wire speed. Shandilya et al. [13] investigated the machining variables on cutting speed in wire EDM of Al6061 reinforced with SiC MMC. They found that the cutting speed was affected more from servo voltage compared with pulse-off time and wire feed rate. Satish Kumar et al. [14] produced Al 6063 reinforced with SiC at different weight fractions and examined the influence of cutting variables on surface roughness and MRR during the wire EDM process. Surface roughness and MRR were affected by the amount of the SiC reinforcement ratio and decreased the surface finish and MRR depend on the increasing reinforcement content. Pal Garg and Sharma [15] studied the dimensional error during the wire EDM process of Al6063 based metal matrix composite reinforced with ZrSiO4p. They have used the pulse-on time, pulse-off time, servo voltage and peak current as the machining parameters and investigated their effect on the dimensional error. Authors were reported that the dimensional error was increased with the increasing the pulse on time and peak current and the pulse off time and servo voltage were not showed a significant effect on the dimensional error.

When the literature reviewed, it was seen that the cutting properties of the Al 6061 based MMCs reinforced by different weight volume fraction of $B_4C$ in wire EDM process have not been investigated enough. Hence, mechanical test specimens of Al 6061/$B_4C$ MMCs were cut using wire EDM with different machining variables and investigated the effect of the cutting parameters on surface roughness during the machining process. The optimal machining parameter and significant ratio were determined using ANOVA and main effect graphs.

## II. Experimental Procedures

Four Al 6061 composite specimens reinforced with 5 wt.%, 10 wt.%, 15 wt.% and 20 wt.% $B_4C$ were manufactured to investigate the effect of the mechanical, machinability and ballistic performance. Powder metallurgy and hot-extrusion techniques were used to produce the specimens. The mean particles size of $B_4C$ was 10µm and Al 6061 powders had average size of 100 µm. Aluminum and $B_4C$ powders were weighed and mixed in a three-dimensional mixer to achieve uniform particle dispersion. Then, each specimen was sintered in a furnace at 550 $^oC$ temperature for 60 minutes after cold pressing process under 300 MPa. Sintered specimens were extruded using pre-heated mold and then subjected to the T6 heat treatment process to increase the mechanical properties. Finally, hot rolling process was performed to the produced specimens to achieve uniform and desired thickness. Particle distribution was examined using a Leica DM4000M microscope and optical images of machined surfaces were presented in Fig. 2. The composite specimens were machined on the Mitsubishi MV1200 series CNC WEDM using computer aided manufacturing (CAM) program. Technical drawings of specimens were designed according to the mechanical tests standard and CNC G-codes generated from CAM. Overview of the experimental setup and produced mechanical test specimens can be seen in Fig. 1. Wire EDM process was performed using a brass wire electrode of diameter 0.30 mm and deionized water was used as the dielectric fluid. Mitutoyo surftest SJ210 was used to measure the machined surface of the composite specimens. Surface roughness measurements were conducted at six different areas, eliminated maximum and minimum values and then, computed the mean surface roughness value. WEDM variables and their machining levels used in the WEDM of specimens are given in Table I.

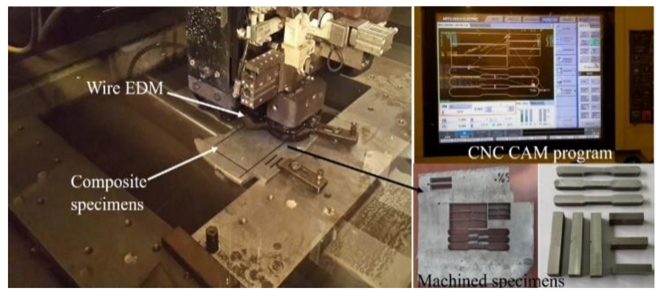


Figure 1. Overview of the experimental set-up for WEDM machining

TABLE I. WEDM Process Parameters with Their Levels

| *Factor* | *Process parameters* | *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* |
|---|---|---|---|---|---|---|
| A | Type of specimen (MT) | Al6061 | 5wt%$B_4C$ | 10wt%$B_4C$ | 15wt%$B_4C$ | 20wt%$B_4C$ |
| B | Peak current, IP (A) | 10 | 12 | 14 | 16 | |
| C | Voltage, C (V) | 45 | 55 | 68 | 80 | |

## III. Experimental Results and Discussion

This study was performed to observe the cutting behavior of composite specimens reinforced with different amount of $B_4C$. Then, surface texture of the machined samples was evaluated and analyzed the particle dispersion in the matrix structure. The optical images showed that the reinforcement powders were uniformly dispersed in the matrix structure and obtained a good interfacial bonding between matrix and $B_4C$ particles (Figure 2).

The purpose of this study is to determine the effect of wire-EDM machining parameters on the surface roughness during cutting of $B_4C$ reinforced metal matrix composite. The effects of spark gap voltage, peak current and wire tension on surface roughness using a brass electrode were investigated. Figure 3 depicts the influence of the reinforcement amount of $B_4C$ ratio, spark gap voltage and peak current on the average quality of surface roughness during wire-EDM of composite specimens. It can be seen from 3D graphs and mean effect graphs that surface quality was improved with increasing reinforcement ratio of $B_4C$. This could be attributed to the reducing built –up edge (BUE) formation due to the increasing hardness values with increasing volume fraction of $B_4C$ on the wire during cutting process. However, more wire breakages were prominently observed with increasing reinforcement ratio of the $B_4C$ particles.

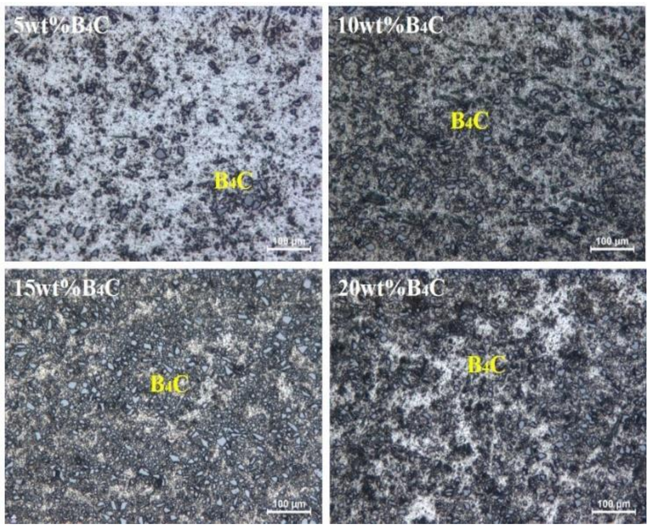


Figure 2. Optical micrographs for B4C particle distribution in matrix structure

WEDM is a non-contact thermal cutting process using high frequency electric discharges to remove material from the work piece leaving kerfs. The electric discharges happen between the work piece and wire electrode in a dielectric fluid at the minimum distance. On the other hand, ceramic particles acted as insulating material in the matrix structure and interrupted the electric discharges during the machining process. it is assumed that the wire tool breakage was occurred as a result of this phenomena [16].

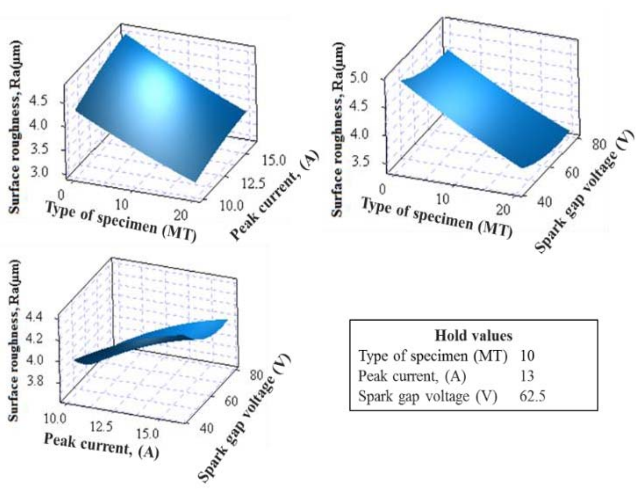


Figure 3. 3D response surface plots relationship between the WEDM parameters

The machined surface roughness values were slightly worsened with increasing peak current parameters due to the increasing cutting speed at higher peak current. Hence, the best surface roughness values were measured at lower peak currents. It can be seen from the mean effect plots that surface quality improved slightly at the beginning and then improved very rapidly with the increase in the voltage from 55 V to 68 V. Later, surface quality decreased with an increase in the voltage to 80 V (Fig.4).

The optimal machining parameters for surface roughness were obtained as a peak current of 10 A, spark gap voltage of 68 V during wire EDM of 20wt% $B_4C$ composite specimen and the measured optimal surface roughness value was 3.18 µm.

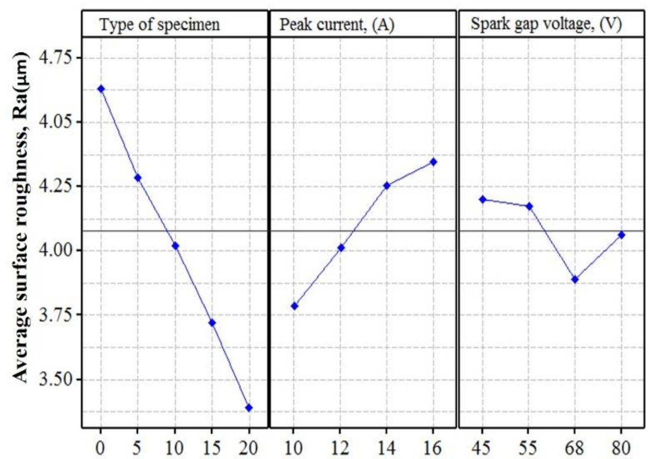


Figure 4. Effect of machining parameters on surface roughness

P and F values of wire EDM parameters on surface roughness were tested at the 95% confidence level by using analysis of variance (ANOVA). The wire EDM variables, P values, and their statistical effect ratio for surface quality are given in Table II.

TABLE II. ANALYSIS OF VARIANCE OF SURFACE ROUGHNESS

| Source | DF | Seq SS | Adj MS | F | P | Effect ratio |
|---|---|---|---|---|---|---|
| Regression | 3 | 3.4964 | 1.1655 | 190.328 | 0.00000 | $R - S_q$ = 97.61% |
| MT | 1 | 2.8544 | 2.5289 | 413.001 | 0.00000 | 80% |
| IP | 1 | 0.4132 | 0.4007 | 65.443 | 0.00012 | 12% |
| C | 1 | 0.2289 | 0.2289 | 37.381 | 0.000268 | 6% |
| Error | 14 | 0.0857 | 0.0061 | | | 2% |
| Total | 17 | 3.582 | | | | |

As shown in Table II, surface roughness was significantly affected from the reinforcement amount of $B_4C$ ratio with an 80% contribution of total variation. The influence ratio of the peak current and spark gap voltage was computed with a percentage contribution of 12% and 6% respectively.

The following regression analysis equation was generated for surface roughness in the wire EDM of metal matrix composite specimens reinforced with 5 – 20 wt.% $B_4C$. $R^2$ value of the regression equation was as 97.61%.

$$Ra = 4.25212 - 0.0580425 * MT + 0.0680501 * IP - 0.00860706 * C \quad (1)$$

## IV. Conclusions

In this study, Al 6061 based MMCs reinforced with four different weight fraction of $B_4C$ were manufactured using powder metallurgy and hot extrusion technique. Standard mechanical test specimens of MMCs were cut in wire EDM based on Taguchi $L_{18}$ ($2^1$ x $3^2$) with a mixed orthogonal array. Then, we investigated the wire cutting performance and surface roughness quality of machined part. The test results were evaluated using analysis of variance and main effect plot. The experimental findings can be summarized as follow:

- The uniform $B_4C$ particle distribution was achieved in all composite specimens and observed a good interfacial bonding between matrix and reinforcement particles.
- The wire breakage behavior was prominently increased with increasing reinforcement ratio of the $B_4C$ particles.
- The surface quality of the machined specimens was improved with increasing $B_4C$ particle reinforcement ratio and reinforcement amount of $B_4C$ was the most effective parameter for the surface quality with an 80% contribution of total variation.
- The surface quality was decreased with increasing peak current and improved with increasing spark gap voltage.
- The best wire EDM machining parameters for surface quality were achieved as a peak current of 10 A, spark gap voltage of 68 V during wire EDM of 20wt% B4C composite specimen and the measured optimal surface roughness value was 3.18 µm.

Future work can be study on the prevent the wire breakage during the cutting process of MMCs

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