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MACHINABILITY STUDIES ON AN Al7075 COMPOSITE WITH VARYING AMOUNTS OF B_4C USING AN INDUCTION-HEATED ELECTROLYTE IN ELECTROCHEMICAL MACHINING

ŠTUDIJA MEHANSKE OBDELOVALNOSTI KOMPOZITOV NA OSNOVI Al7075 Z RAZLIČNO VSEBNOSTJO B_4C PRI UPORABI INDUKCIJSKO OGREVANEGA ELEKTROLITA IN ELEKTROKEMIČNE OBDELAVE

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Electrochemical machining (ECM) is one of the important machining processes for machining alloys and composites. Aluminum metal matrix composites (AMMCs) are increasingly gaining in importance in the aerospace and automobiles industries. In this research the metal matrix composite (MMCs) is fabricated using the aluminum alloy (7075) with 5 % mass fraction of B_4C and 10 % mass fraction of B_4C in two different proportions as reinforcement. AMMCs (Al7075 with 5 % mass fraction of B_4C and Al7075 with 10 % mass fraction of B_4C) specimens were fabricated through a stir-casting process. The comparative study of the machinability of these composites is proposed using ECM. The input parameters like electrolyte temperature, electrolyte concentration, voltage and duty cycle were chosen and machining speed, overcut and delamination factor (DF) are considered as an output response. Sodium nitrate is used as an electrolyte and the electrolyte is heated by an induction heater to maintain the temperature during the machining, which was monitored continuously with a thermocouple. Based on conducted experiments the machining speed increases with the electrolyte temperature. The specimen of Al7075 with 10 % mass fraction of B_4C composite shows a lower overcut and DF during the ECM process. Based on a Scanning Electron Microscope (SEM) image it is evident that the proper circular holes were obtained on the AMMC specimens (Al7075 with 5 % mass fraction of B_4C and Al7075 with 10 % mass fraction of B_4C). The EDAX analysis and Rockwell hardness test were performed to study the mechanical properties of the specimen.

Keywords: electrochemical machining (ECM), electrolyte temperature, composite aluminum 7075, boron carbide (B_4C), SEM, EDAX

Elektrokemijska obdelava (ECM) je pomemben postopek mehanske obdelave kovinskih zlitin in kompozitov. Kompoziti z matrico na osnovi Al zlitin postajajo vedno pomembnejši materiali v letalski in avtomobilski industriji. V članku avtorji opisujejo raziskavo obdelovalnosti (vrtanja izvrtin) kompozitov z matrico iz Al zlitine (Al7075) in dvema različnima vsebnostma B_4C (5 mas. % in 10 mas. %) kot ojačitvene faze. Vzorci kompozitov so bili izdelani s postopkom premešavanja in ulivanja (angl.: stir casting process). Avtorji prispevka so izdelali primerjalno študijo ECM obdelovalnosti obeh kompozitov. Za vhodne parametre so izbrali temperaturo elektrolita, njegovo koncentracijo, napetost in storilnost, medtem ko so bili odgovorjajoči izhodni parametri hitrost obdelave, prekomerni odrez in delaminacijski faktor (DF). Za elektrolit so izbrali natrijev nitrat, ki so ga indukcijsko ogrevali na željeno temperaturo. Le-to so konstantno nadzirali s termočlenom. Na osnovi preizkusov so ugotovili, da je hitrost mehanske obdelave (odvzema materiala med vrtanjem) naraščala z naraščajočo temperaturo elektrolita. Vzorci kompozita z 10 mas.% B_4C so imeli manjši prekomerni odrez in DF po izvedenem ECM procesu. Na osnovi mikroposnetkov izdelanih z vrstičnim elektronskim mikroskopom (SEM) so ugotovili, da so med obdelavo obeh kompozitov (Al7075 s 5 mas. % B_4C oz. z 10 mas.% B_4C), nastajale pravilne okrogle izvrtine v kompozitu. Na vzorcih kompozitov so izvedli tudi analize z energijsko disperzijsko spektroskopijo rentgenskih žarkov (EDAX) in meritve trdote po Rockwellu.

Ključne besede: elektro-kemijska mehanska obdelava (ECM), temperatura elektrolita, kompozit na osnovi 7075, ojačan z borkarbidom (B_4C), SEM, EDAX

1 INTRODUCTION

ECM is a non-conventional machining process for machining difficult-to-cut materials and MMCs. AMMCs are considered in the aerospace, marine and automobile industries due the physical properties like light weight, good strength, easy to machine and cost effective. The selection of Al7075 alloy as the matrix and B_4C as the reinforcement improves the properties of the metal matrix composites. The presence of B_4C improves the wear resistance, impact strength and also withstands chemical and thermal reactions. The fabrication of a new MMC will result in improved features; however, it leads to certain constraints like machinability issues especially during the drilling of micro-holes. S. Ramesh V. Subburam[1] studied the influence of

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Table 1: Chemical compositions (weight %) of Al7075

Element	Zn	Mg	Cu	Fe	Si	Ti	Mn	Cr	Al	Other
Weight %	5.6	2.5	1.5	0.5	0.4	0.2	0.3	0.25	87.1 to 91.4	0.15

voltage, current and pulse-on time on response parameters such as machining speed and overcut for an aluminum composite containing a ceramic reinforcement. Based on the experiment they observed that at higher input values the machining speed was higher with a lower accuracy. C. S. Kalra et al.[2] investigated the machining of a micro-hole in hybrid composites and showed an increase in the electrical parameters and the metal removal rate was high, also it leads to more overcut. R. Thanigaivelan et al.[3] have studied the effect of electrolyte heating and concluded that the MRR increases with an increase in the electrolyte. M. Sankar et al.[4] investigated the machining of aluminum B_4C composites in ECM using an abrasive-assisted electrolyte in which the surface finish was good and accurate. M. A. H. Mithu et al.[5] have analyzed the effect of electrolyte temperature in the machining of nickel using ECM. C.T. M. Jegan et al.[6] analyzed the machining parameters of the MMC (AA6061 with SiC for different composition) in ECM in which the metal removal rate (MRR) increases with an increase in the input value. S. Ayyappan et al.[7] analyzed the cost for machining the MMCs in the ECM. The study revealed that the electrical parameters and the tool feed rate have a large effect on the machining cost. A. D. Davydov et al.[9] increased the electrolyte temperature and concluded that the heating of the electrolyte achieves better dimensional accuracy and improved machining efficiency. M.Hackert-Oschatzchen et al.[10] analyzed the effect of the electrical input (pulsed) on the machining of AMMCs in ECM and it is evident from the results that a good surface finish was obtained for a low current density.

The above literature highlights the ECM of MMC and the electrochemical reaction rate increases with an increase in the electrolyte concentration, temperature, or a decrease in the pH value. Based on the above literature only sparse data is available on the ECM of MMCs; therefore, in this research paper the focus is on an investigation of the effect of electrolyte temperature and concentration on machining of the composite Al7075 with a varying composition of B_4C. The machining speed, overcut and DF are considered as response factors and the SEM images with an EDAX test were performed to study the microstructure of the MMC.

2 EXPERIMENTAL PART – FABRICATION OF MMC AND MACHINING IN ECM

2.1 Fabrication of metal matrix composite (AL7075 with 5 % mass fraction of B_4C AND AL7075 with 10 % mass fraction of B_4C)

Stir casting is a simple method for the fabrication of MMCs. There has been extensive research carried out regarding the reinforcement distribution in the matrix and mechanical properties of the MMC. The literature reveals that the microstructure evolution depends on the stirring time, and hence careful considerations are given to the fabrication of the composite of Al7075 with B_4C. **Table 1** presents the chemical composition of the Al7075. The MMCs are fabricated using the aluminum alloy (7075) with varying compositions of B_4C. AMMCs (Al7075 with 5 % mass fraction of B_4C and Al7075 with 10 % mass fraction of B_4C) specimens were fabricated through a stir-casting process. In this process the Al7075 is melted and further mixed along with B_4C powder (5 % mass fraction of B_4C and 10 % mass fraction of B_4C) in a stir-casting machine for one hour. Simultaneously, the stirring mechanism in the crucible is carried out to ensure a thorough mix of the reinforcement in the matrix. When the required temperature is reached, the molten MMC is poured into the pattern to obtain the required specimen (plate with 1.5 mm thickness).

2.2 Electrochemical machining

L. Tang et al.[8] studied the effect of using different types of electrolytes on machining S03 stainless steel using ECM. The experimental results highlighting the use of sodium chloride had a better machining rate and surface roughness. R. Thanigaivelan et al.[11] investigated the effect of using an acidified sodium nitrate electrolyte when machining the stainless steel in ECM. It was found that the *MRR* and the accuracy are greatly affected by the electrolyte type. The increase in temperature goes together with the reaction rate. Temperature is a measure of the kinetic energy of an electrochemical system, so a higher temperature entails a higher average kinetic energy of molecules and more collisions per unit time. In general, the chemical reactions will approximately double for each 10 °C increase in temperature. Hence the heated electrolyte is considered for the ECM to improve machining efficiency.

The inbuilt electrochemical set-up consists of an electrical pulse power supply, controlled motion system for feeding the tool. An induction heater is placed in the electrolyte bath to maintain the selected temperature during machining. The electrolyte circulation system

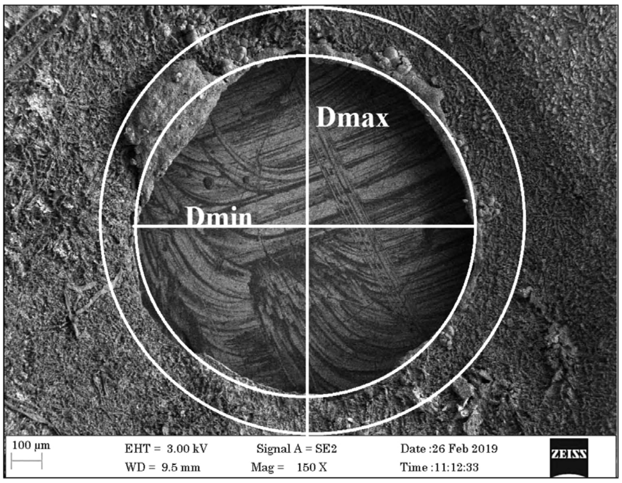

Figure 1: Delamination factor

was not utilized during the experimentation as circulation of electrolyte can reduce the electrolyte temperature. The ECM set up has a workpiece holder and immersed in an electrolyte of varying concentration. The control panel consists of four parameters which can be varied, i.e., voltage, current, duty cycle and frequency. The tool feeder is controlled by a stepper-motor mechanism, which is operated manually to maintain the gap between the electrode and the workpiece. The sodium nitrate was selected as the electrolyte and it is heated using an induction heater.

The tool holder is accurately aligned and fixed to the stepper-controlled mechanism, which is perpendicular to the workpiece. In the workpiece fixture, the specimen is clamped in proper alignment with the tool during the machining. In each experiment the time taken for through hole is measured for calculating the machining speed, considering the thickness of the workpiece. The completion of machining is ensured by the evolution of gas bubbles beneath the workpiece. The overcut is calculated by obtaining the difference in diameter of the machine hole diameter and the tool diameter. **Figure 1** shows the delamination lamination of the machined hole and the delamination factor is obtained from the ratio of D_{max} to D_{min}, where D_{max} is the maximum diameter and D_{min} is the minimum diameter.

2.2.1 Machining process

The experimental investigation was made in an ECM machine to examine the influence of various process parameters such as the electrolyte concentration, electrolyte temperature, voltage and duty cycle by varying one parameter at a time, which is shown in **Table 2**. The conditions for the tests were selected to cover the range of realistic machining parameters for sufficient accuracy of the subsequent analysis. The workpiece was fixed in the fixture and the electrode gap was set as near as possible to the expected equilibrium gap to reduce the time delay in reaching the equilibrium condition. The inter electrode gap is maintained by making the tool and the workpiece touch and later the stepper motor is reversed to achieve the required gap of 32 µm. The electrode will move in both the forward and reverse directions for 4 µm/pulse. The connectivity of the anode and cathode was checked. Initial tests were conducted and micro holes were drilled based on the input parameters.

The micro holes were drilled on the composite specimen Al7075 with 5 % mass fraction of B_4C and in the specimen Al7075 with 10 % mass fraction of B_4C, and the output parameters like the machining speed, overcut and DF of the micro-holes were analyzed. Both the composite specimens were fabricated with a thickness of 1.5 mm. The stainless-steel tools were selected with a diameter of 0.5 mm. The inter-electrode gap was maintained to ensure the smooth machining of the micro-holes. The experimental setups were designed by varying one input parameter at a time and in total 20 experiments were designed for each specimen. The experiments were conducted on the specimen, 40 sets of experiments were completed and presented in the **Table 3**. The frequency of the power supply was kept constant at 90 Hz. The machined micro-hole surfaces were scanned in the SEM to study the surface finish. The EDAX tests were performed to analyze the distribution of the reinforcement in the composite materials.

Table 2: Machining parameters with 5 levels

Parameters	Level 1	Level 2	Level 3	Level 4	Level 5
Electrolyte concentration, g/L	20	25	30	35	40
Electrolyte temperature, °C	27	30	33	36	39
Voltage, V	9	10	11	12	13
Duty cycle, %	50	60	70	80	90

3 RESULTS

Table 3: Experimental combination for machining the composite specimen Al7075 with 5 % mass fraction of B_4C and the specimen Al7075 with 10 % mass fraction of B_4C

S. No	Electrolyte concentration NaNo3, g/L	Electrolyte temperature, °C	Voltage, V	Duty cycle %	Al 7075 with 5 % mass fraction of B_4C			Al 7075 with 10 % mass fraction of B_4C		
					Machining Speed, mm/min	Over cut, µm	DF	Machining Speed, mm/min	Over cut, µm	DF
1	40	39	9	90	0.0625	335	1.1605	0.0517	303	1.1509
2	40	39	10	90	0.0714	394	1.1763	0.0750	534	1.2066
3	40	39	11	90	0.1000	453	1.1901	0.0938	563	1.2119
4	40	39	12	90	0.1500	479	1.1957	0.1250	700	1.2333
5	40	39	13	90	0.2143	1296	1.2886	0.1667	1242	1.2852
6	40	39	13	50	0.05000	163	1.0983	0.05556	315	1.1546
7	40	39	13	60	0.07500	222	1.1230	0.08824	443	1.1879
8	40	39	13	70	0.09375	232	1.1268	0.10000	700	1.2333
9	40	39	13	80	0.13636	453	1.1901	0.13636	796	1.2457
10	40	39	13	90	0.21429	1109	1.2757	0.16667	1161	1.2796
11	40	27	13	90	0.08333	412	1.1807	0.04286	334	1.1602
12	40	30	13	90	0.05000	606	1.2192	0.06000	700	1.2333
13	40	33	13	90	0.08333	610	1.2198	0.07895	975	1.2644
14	40	36	13	90	0.15000	1160	1.2795	0.10000	1094	1.2745
15	40	39	13	90	0.21429	1534	1.3017	0.16667	1105	1.2754
16	20	39	13	90	0.04286	453	1.1901	0.03750	437	1.2333
17	25	39	13	90	0.05000	463	1.1923	0.04167	700	1.2639
18	30	39	13	90	0.07895	937	1.2608	0.06000	970	1.2760
19	35	39	13	90	0.10000	1340	1.2913	0.07500	1113	1.2772
20	40	39	13	90	0.21429	1568	1.3033	0.16667	1129	1.2796

4 DISCUSSION

4.1 Effect of electrolyte temperature on machining speed, overcut and DF

It is evident from **Figure 2a** that the machining speed increases with an increase in the electrolyte temperature. In ECM, material removal occurs under the influence of a potential difference. On comparing the different composition reinforcement, the specimen Al7075 with 10 % mass fraction of B_4C shows better machinability than the specimen Al7075 with 5 % mass fraction of B_4C. This is due to the fact that at a higher composition of reinforcement, the presence of B_4C in the MMC is not dissolved by the current efficiency. At the same time the dissolution of the metal matrix happens at a quicker phase, leading to bulk removal of the material. Hence, the percentage of B_4C contributes to the high dissolution of the metal matrix. At 30 °C the machining speed is 0.060 mm/min and increases to 0.21 mm/min with an increase in the electrolyte temperature up to 39 °C. Hence, it is evident that the use of a heated electrolyte improves the electrolyte ion kinetics, which contributes to a higher machining speed. **Figure 2b** shows the effect of the overcut on the electrolyte temperature. The overcut for the specimen Al7075 with 10 % mass fraction of B_4C is found to be lower compared to the specimen Al7075 with 5 % mass fraction of B_4C. The insulating nature of the reinforcement and the hydrogen gas bubble generation contributes to a lower overcut. Based on **Figure 2c** it is evident that the DF increases with an increase in the electrolyte temperature. For the specimen Al7075 with 5 % mass fraction of B_4C the DF

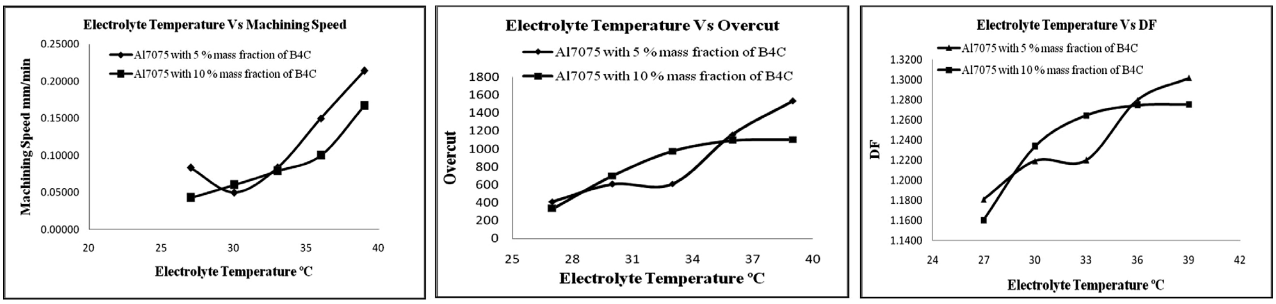

Figure 2: a) Effect of heated electrolyte on the machining speed, b) effect of heated electrolyte on the overcut, c) effect of heated electrolyte on the DF

first increases and then drastically increases with the temperature. The DF is found to be 1.3 at 39 °C and reduces to 1.19 as the temperature reduces to 27 °C.

4.2 Effect of electrolyte concentration on the machining speed, overcut and DF

Figure 3a shows the effect of the electrolyte concentration on the machining speed. The machining speed for the specimen Al7075 with 5 % mass fraction of B_4C is higher compared to the specimen Al7075 with 10 % mass fraction of B_4C. It is evident from **Figure 3a** that the machining speed increases for the high electrolyte concentration, which is attributed to the increase in the chemical reactions between the tool and the composite material. **Figure 3b** shows that the increase in the electrolyte concentration increases the overcut and DF for the specimen Al7075 with 5 % mass fraction of B_4C. The overcut and DF are found to be less for the specimen Al7075 with 10 % mass fraction of B_4C. At 20 g/L the overcut is found to be 437 µm and increases with an increase in the electrolyte concentration. At higher concentrations the overcut was found to be 1129 µm. It is clear from **Figure 3c** that the DF increases with the electrolyte concentration. This is due to the fact that with an increase in the electrolyte concentration the ions required for dissociation increase and hence more material removal occurs from the specimen. Additionally, the electrolyte heating increases the temperature, which increases the mobility of the chemical reactions contributing a higher DF. At higher electrolyte temperature the ions attack the material in close vicinity to the electrode then the more distant area of the specimen, resulting in the partial dissociation of the material contributing to a higher DF. The DF for the specimen Al7075 with 5 % mass fraction of B_4C increases drastically for the range of 25 g/liter to 40 g/liter. On comparing the DF for the specimen Al7075 with 10 % mass fraction of B_4C with the specimen Al7075 with 5 % mass fraction of B_4C shows 3.6 % higher value at 20 g/liter. Moreover, the DF is found to be less for the specimen Al7075 with a 10 % mass fraction of B_4C at a higher electrolyte concentration. The use of electrolyte heating reduces the viscosity of the electrolyte leading to a smaller overcut and DF.

4.3 Effect of electrical parameters on the machining speed, overcut and DF

The increase in electrical parameters, such as voltage and duty cycle, shows higher machining speed, overcut and DF, as shown in **Figure 4a** and **Figure 4b**. The machining speed for the specimen Al7075 with 5 % mass fraction of B_4C is found to be higher when compared to the specimen Al7075 with 10 % mass fraction of B_4C. The machining speed is found to be 0.0625 mm/min and increases to a maximum value of 0.2143 mm/min for the specimen Al7075 with 5 % mass fraction of B_4C. Based on **Figure 5a** and **Figure 5b** the

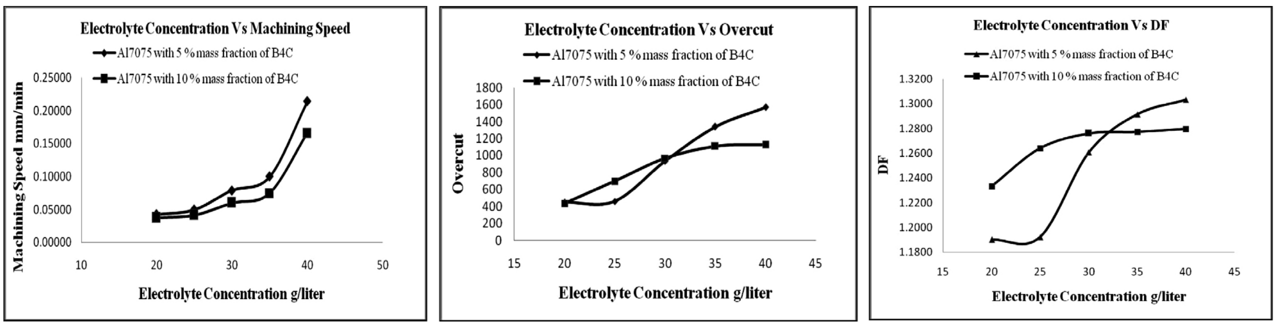

Figure 3: a) Effect of electrolyte concentration on the machining speed, b) effect of electrolyte concentration on the overcut, c) effect of electrolyte concentration on the DF

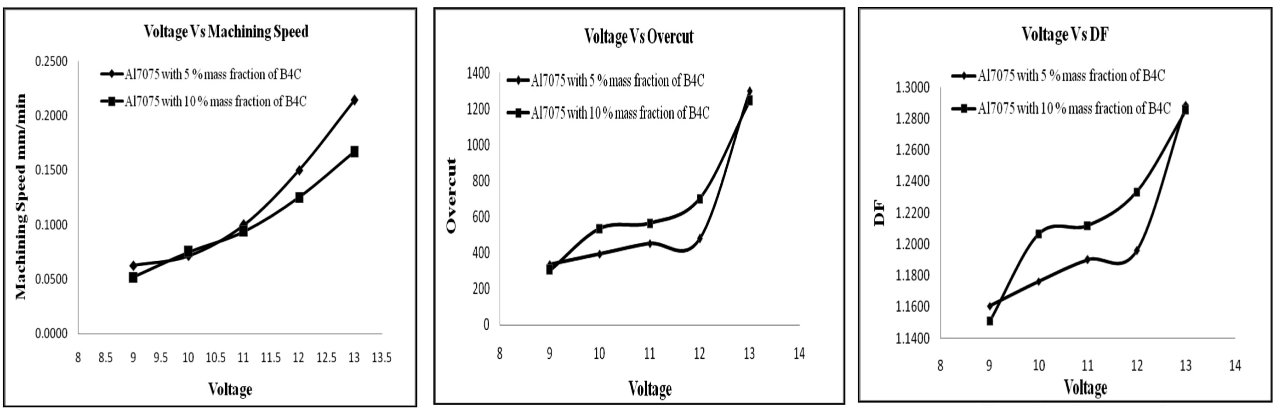

Figure 4: a) Effect of voltage on the machining speed, b) effect of voltage on the overcut, c) effect of voltage on the DF

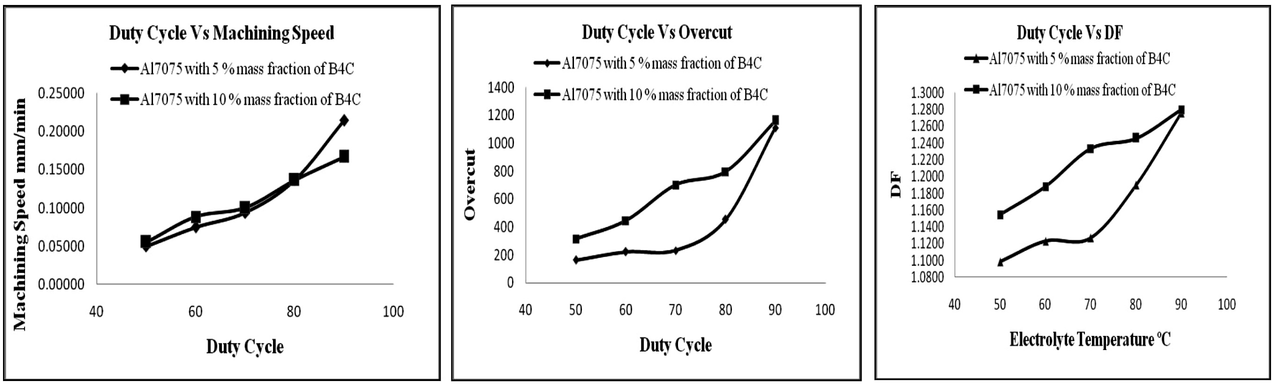

Figure 5: a) Effect of duty cycle on the machining speed, b) effect of duty cycle on the overcut, c) effect of duty cycle on the DF

increase in duty cycle improves the machining speed. By the way increasing the duty cycle the current density required for machining keeps on increasing, leading to more dissolution of the specimen Al7075 with 5 % mass fraction of B_4C and other responses, such as overcut and DF for the specimen Al7075 with 10 % mass fraction of B_4C shows better results. At 9 V the machining speed for the specimen Al7075 with 5 % mass fraction of B_4C is found to be 0.0625 mm/min and increases to 0.2143 mm/min at 13 V. Similarly, the machining speed for 50 % duty cycle is 0.050 mm/min and increases to 0.214 mm/min at 90 % of duty cycle. The overcut value for 9 V is found to be 315 µm and increases to 1161 µm for 12 V. With an increase of the duty cycle from 50 % duty cycle to 90 % duty cycle the DF varies in the range of 1.15 to 1.27. By varying the voltage from 9 V to 13 V the DF tends to vary between 1.15 to 1.28.

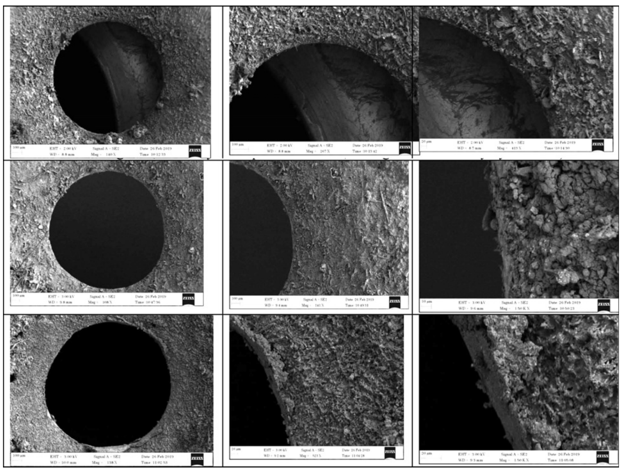

Figure 6: SEM Images: a) specimen 2: Al7075 with 10 % mass fraction of B_4C (hole machined with electrolyte concentration 40 g/L, electrolyte temperature 39 °C, voltage 13 V and duty cycle 90 %), b) specimen 2: Al7075 with 10 % mass fraction of B_4C (hole machined with electrolyte concentration 40 g/L, electrolyte temperature 39 °C, voltage 10 V and duty cycle 50 %), c) specimen 1: Al7075 with 5 % mass fraction of B_4C (hole machined with electrolyte concentration 20 g/L, electrolyte temperature 39 °C, voltage 10 V and duty cycle 50 %)

4.4 SEM analysis

The SEM analysis was performed to study the surface morphological features of the specimen machined in ECM. The specimen is thoroughly cleaned using acetone in an ultrasonic vibrator and analyzed in the SEM. The surface morphological structure of the specimen was obtained using a ZEISS SEM at an accelerating voltage of 20 kV. The machined specimen of Al7075 with B_4C 5 % mass fraction of B_4C and 10 % mass fraction of B_4C was mounted in the SEM and images were taken on the machined surfaces. The SEM images in **Figures 6a** to **6c** show the circularity feature of the hole. Moreover, the heated electrolyte introduced a more delaminated area around the circumference of the hole. The heated

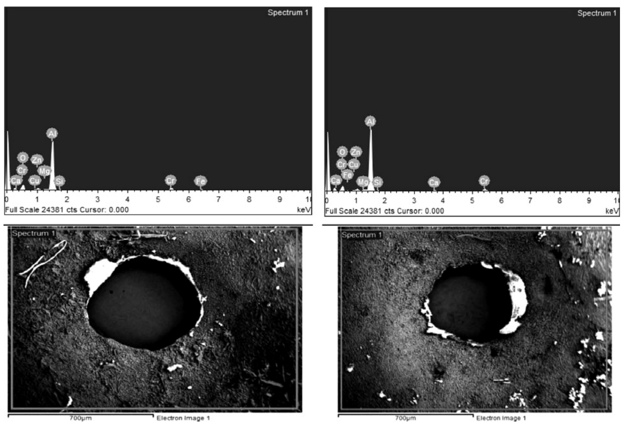

Figure 7: EDAX Test Results

Figure 7a: Specimen 1: Al7075 with 5 % mass fraction of B_4C			**Figure 7b:** Specimen 2: Al7075 with 10 % mass fraction of B_4C		
Element	Weight %	Atomic %	Element	Weight %	Atomic %
O K	24.38	37.88	O K	21.13	33.61
Mg K	0.73	0.74	Mg K	0.75	0.79
Al K	57.05	52.56	Al K	60.28	56.86
Si K	1.33	1.18	Si K	0.86	0.78
Cl K	0.82	0.57	Cl K	0.46	0.33
Ca K	0.68	0.42	Ca K	1.27	0.81
Cr K	6.82	3.26	Cr K	6.96	3.41
Fe K	3.91	1.74	Fe K	2.60	1.19
Cu K	1.22	0.48	Cu K	1.76	0.70
Zn K	3.08	1.17	Zn K	3.92	1.53
Total	100.00		Total	100.00	

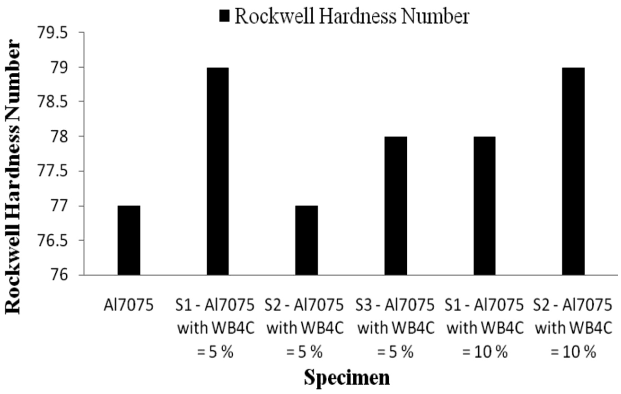

Figure 8: Rockwell hardness numbers from the experiments

electrolyte flow formed more pits on the surface of the hole's circumference. **Figure 6c** shows the increase in the electrolyte temperature, leading to the formation of more craters on the circumference of the micro-hole. At higher temperature the mobility of ions near the machining zone increases, leading to the formation of more micro-craters.

4.5 EDAX test

To determine the rate of penetration of each aluminum composite, XRD microdiffraction of the B_4C are shown in **Figure 7**. The XRD peak list of the Al7075 with B_4C (both the specimens) are listed in the tables. The EDAX analysis reveals the variable dispersion of the reinforcement in the matrix.

4.6 Rockwell hardness

The Rockwell hardness tests were performed to measure the hardness of the specimen. In a Rockwell hardness testing machine, a 1/8" ball penetrator with a maximum load of 100 kg was used to measure the depth of the indentation.

The Rockwell hardness test was performed and the results in **Figure 8** show that the addition of boron carbide increases the hardness of the specimen. During the fabrication of the MMC the chance of agglomeration with respect to reinforcement occurs during the solidification process and results in an uneven distribution of the reinforcement in the matrix. This results in different hardness values for the specimens.

5 CONCLUSIONS

An experimental investigation was made in an ECM machine to examine the influence of various process parameters, such as the electrolyte concentration, electrolyte temperature, voltage and duty cycle on the machining of micro-holes in the composite Al7075 with B_4C (5 % mass fraction of B_4C & 10 % mass fraction of B_4C). The results obtained are as follows:

- The machining speed increases with the electrolyte temperature. For the same parametric input combinations the specimen Al7075 with 5 % mass fraction of B_4C shows a higher machining speed than the specimen Al7075 with 10 % mass fraction of B_4C. At 30 °C the machining speed is 0.060 mm/min and increases to 0.21 mm/min with an increase in the electrolyte temperature up to 39 °C.
- The specimen Al7075 with 10 % mass fraction of B_4C composite shows a lower overcut and DF during the ECM process. The overcut value of 9 V is found to be 315 μm and increases to 1161 μm for 12 V. With an increase in the duty cycle from 50 % to 90 % the DF varies in the range of 1.15 to 1.27. By varying the voltage from 9 V to 13 V, the DF tends to vary between 1.15 to 1.28.
- The SEM image obtained for the specimen AL7075 with 5 % of mass fraction of B4C shows good surface topography hole at parametric combination of 20 g/L, electrolyte temperature of 39 °C, voltage of 10 V and duty cycle of 50 %. Moreover for the specimen Al7075 with 10 % of mass fractions of B_4C the microhole generated shows good circular profile for the parametric combination of 40 g/L, electrolyte temperature of 39 °C, voltage of 13 V and duty cycle of 90 °C.
- EDAX analysis reveals the variable dispersion of the reinforcement in the matrix.
- The Rockwell hardness test was performed and the results show that the addition of boron carbide increases the hardness of the specimen.

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