Material removal characteristics of Al-SiO_2 composite in WEDM

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Abstract

Demand for particle reinforced composite materials gradually increases and that leads to the use of inexpensive particles or solid waste particles as a reinforcement phase to lower the cost of the composite. Silica sand (SiO_2) is an industrial waste that contributes to the strength of the aluminium matrix. Therefore, an attempt is made to use 10 wt. % of silicon dioxide as hardening of particles to obtain composite materials with an aluminium matrix. A stir casting method was used to produce the aluminium matrix. The mechanical and optical microstructural properties of the newly developed Al /SiO_2 composites were studied. Al / SiO_2 composites were processed using wire electrical discharge machining (WEDM) to optimize processing parameters such as pulse-on time (μs), pulse-off time (μs) and current (A) to improve material removal rate (MRR). The model was confirmed and good agreement was reached.

Keywords: composite, reinforcement, aluminium, matrix, parameters, current, model, microstructural

Kulcsszavak: kompozit, megerősítés, alumínium, mátrix, paraméterek, áram, modell, mikroszerkezet

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1. Introduction

Composite materials, which are usually reinforced with microstructured particles in metal matrices, have the ability to obtain the properties of individual materials. Metal matrix composites (MMC) make it easier for companies involved in the processing of raw materials and the production of goods in factories to meet current and future requirements.Currently, the devotion of time and attention to acquiring knowledge on aluminium (Al) on every side of the planet are largely found owing to the fact that its distinctive property of inferior density, hostility to corrosion and exceptionally good mechanical properties [1]. The manufacturing of part or element from aluminum MMCs make them appealing for many structural component where lofty inflexibility, elevated strength and inferior weight are essential. Aluminum is suited to the weight loss applications [2]. In recent times, the aluminum MMCs have attracted throughout the world attention in virtue of their potentiality to replace massive equivalent, mostly in the automotive and energy area. Toughning of aluminum composite by spreading over the area with exquisitely divided ceramic particles has been evolved for the making of materials with superior stiffness for manufacturing industry. Aluminum MMCs were investigated, and it was established that the hardness of composite materials rises with the inclusion of strengthening reinforcements, and superior hardness is by virtue of the existence of tough ceramic matters in the composite [3].

Silica sand is marked as one of the most economical and hard ceramics particles of unambitious density, obtainable in huge amount as a secondary product of solid waste matter in the mass production of a glass factory [4]. The disposal of silica sand powder in a glass factory causes significant economic and environmental problems. The use of quartz sand strengthens the aluminum matrix and offers the advantages of processing industrial waste and reducing processing problems in a glass factory [5]. Therefore, compounds with quartz sand as a reinforcing substance will undoubtedly be beneficial for widespread use in the automotive and aerospace industries. This resarch concentrate on the utilization of unused industrial waste and dispersing it in an aluminum matrix to produce composite by stir casting process [6].The dissertate for this study is the efficient use of quartz sand, which is one of the residual manufacturing products generated in the glass plant, which argument significant economical and environmental problems. The need for high strength composites enhanced by ceramics particles is also gradually rising. Therefore, more efforts are being made to use silica sand waste being dumped in plants as a reinforcement particles to lower the price of the cost of the composite materials.

In the present work, the lack of hardness of pure Aluminum is amplified by incorporating 10 wt. % SiO_2. Wire EDM Process (WEDM) is a potential process that is useful for processing hard-to-manage materials [7]. WEDM is used to process advanced materials with a metal matrix (MMC) and conductive ceramics. Efforts were made to treat freshly prepared Al composite with 10 wt. % SiO_2 back up to hold superior material removal rate (MRR). Measured WEDM coefficients, such as pulse time (μs), pulse turn-off time (μs), and current (A), have been optimized to refine the MRR. Analysis of variance (ANOVA) was put to use as a means of finding the major noteworthy measurable factors in WEDM operation . Taguchi's L9 orthogonal matrices were over-decorated to estimate the net parameter space in just a few experiments.

2. Materials and manufacturing

Pure commercially available Aluminum is taken as a matrix, and 10% via weight of silica is taken as reinforcement. The properties of SiO_2 are proven in *Table 1*. The common particle size of SiO_2 used on this work was 50 μm.Although many production generation had been used for the producing of mining and metallurgical composites, stir casting technology were one of the dominant technology used within the industry. This method is commonly used to produce complex types of materials for the manufacturing industry.

Chemical Properties	
Crystal name	Monoclinic
Mineral name	Moganite
Chemical Formula	SiO_2
Mesh size	230
Size	53 μm
Thermal Properties	
Melting point	1760°C
Boiling Point°C	2240°C
Physical Properties	
Density g/cm³	2.33
Molar mass	59.96 g/mol

Table 1 Properties of silica sand
1. táblázat Kvarchomok tulajdonságai

In addition, the constant propagation of reinforcement in the matrix is very feasible due to constant agitation by the mixer.In this study, to achieve all of these benefits, a method of stir casting method was selected for the manufacture of MMC [8,9]. The required amounts of silica are stored together with a graphite crucible, motor and stirrer. Al-SiO_2 compounds were synthesized using a stirrer.

Pure Aluminum is melted in a coal furnace. A vortex was created at a temperature of 770 °C and then preheated quartz sand was gradually added to the molten metal and then thoroughly mixed with a stirrer for 20 minutes [10]. Uniform dispersion of the reinforcement in the matrix is achieved using a stirrer [11]. The drive speed was 550 rpm. *Fig. 1* shows die casting of a matrix consisting of Aluminum-SiO_2.

Fig. 1 The casting of Al/SiO_2
1. ábra Al/SiO_2 rudak

3. Results and discussion

Since the cutting operation can change the microstructure of the sample due to heating, cutting was done using a low-velocity diamond plate [12]. After assembly, grinding was performed to reduce surface damage caused by cutting discs. The grinding speed was maintained at about 150 rpm and was performed with increasing paper fineness of 240, 400, 600 and 1000. Small scratches caused by the final grinding operation are removed by polishing using powder flakes. *Fig. 2* shows a uniform distribution of reinforcement throughout the matrix. The particle content is smaller since the area is smaller. With a greater growth in the quantity of composite particles, the grain obstacles are visible.Reinforcing particles are dark in colour. The distribution of quartz sand is seen evenly in the Aluminum matrix. This is achieved by vigorous stirring with a stirrer. There are no pores around the quartz sand particles. Besides, there is no matrix region without reinforcement. It has also been found that there is a good interfacial compound in addition to a uniform distribution. The tensile strength (*Fig. 3*) of 0% by mass of Al is 7 MPa, and this value increases to 20 MPa for Al / SiO_2 with the addition of 5% by mass of SiO_2, which shows an improvement of 185% compared to pure Al. Similarly, for 10 wt. % SiO_2, the tensile strength will increase to 29 MPa, that is approximately 315% better than the tensile power of unreinforced Aluminum. This is because the reinforcing particles in the compounds of the metal matrix are evenly distributed. But adding more reinforcing particles leads to agglomeration, which reduces the bond strength between Al and the reinforcing particles. An increase in SiO_2 will lead to greater cracking and consequently to lower tensile strength. Besides, contacts between silica particles will isolate ductile Aluminum.

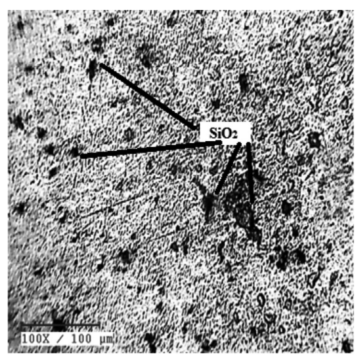

Fig. 2 Microstructure of AMC
2. ábra AMC mikroszerkezete

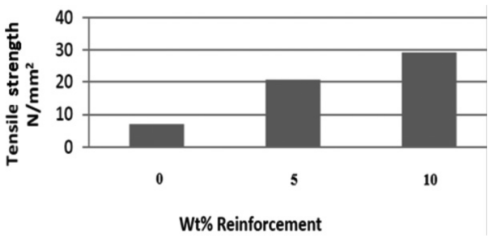

Fig. 3 Tensile strength vs wt % of SiO_2
3. ábra Húzószilárdság SiO_2 tartalom függvényében

As a result of this effect on hardness, it was determined that the value of hardness is better with increased traction. It is also noted that the maximum hardness is attained at Al with 10 wt% SiO_2. The hardness cost of pure Al turned into 26 BHN, which became elevated to 30 BHN with the addition of five wt.% SiO_2 within the Al matrix and 33 BHN for 10 wt.% SiO_2.Improvement of hardness value is achieved for 5 wt% SiO_2 is 15% and similarly, for 10 wt%, SiO_2 is 26%. Increase of the hardness value shows that the addition of silica particles increased to 10%, the hardness increased. This is because the harder SiO_2 particles replace some of the soft Aluminum. However, when the addition of reinforcement increased beyond 10 wt%, the hardness decreased. This is because more silica particle presents in the Al matrix then the bonding becomes poor. Hence beyond the addition of 10 wt% SiO_2 into Al matrix lead to low hardness. *Fig. 4* demonstrates the hardness estimations of the ALMMC. Uniform distribution of SiO_2 into Aluminum matrix would increase hardness and also ductile Aluminum would become a little bit brittle.

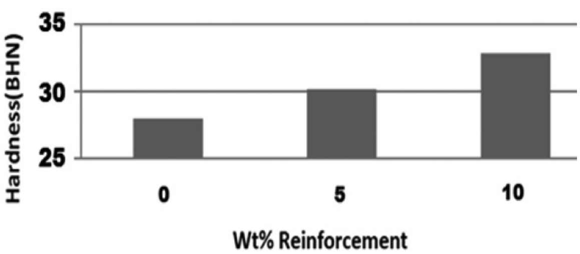

Fig. 4 Hardness vs wt % of SiO_2
4. ábra Keménység SiO_2 tartalom függvényében

The results confirms that 5 wt.% $SiO_2$with aluminium composites gives the yield strength of 22 N/mm^2 which is 100% higher than yield strength of pure aluminium (11 N/mm^2). Similarly, for 10 wt.% SiO_2, the yield strength is 28 N/mm^2, which gives an improvement of 154% compared to unreinforced Al. *Fig. 5* shows the yield strength of the metal matrix composites. The uniform dissemination of SiO_2 in the aluminum lattice essentially improved the yield quality. *Fig. 6* shows that at 5% by mass of SiO_2, a decrease of 5%, 5% by SiO_2 and 3.7% at 10% by mass of SiO_2 is observed, while at 5% by mass of SiO_2 and 10% by mass, a decrease in SiO_2 is achieved using unreinforced Aluminum reaches 80%. Because of warm confound, the Al grid enters the stress state, and SiO_2 particles enter the compression state. Since SiO_2 has low elasticity and a high decrease in compressive quality is accomplished. It was noted that the newly created unaltered aluminum was strengthened by 10 wt. % SiO_2 has high resistance. Since it is very durable, conventional machining may not be suitable for machining operations. Therefore, the experiments were carried out in wire-cut EDM (EDM DK7740), which is shown in *Fig. 7*. Specifications of WEDM machine are given in *Table 2*. Molybdenum wire (DK7740) is used as the electrode wire in the EDM for wire cutting. To ensure a smooth movement of the wire feed, digital circuits controlled by an inverter are used. This molybdenum wire can be used for quite a long time with high accuracy and can reduce wire breakage. The width of the molybdenum wire used in this machining was 0.18 mm. EDM molybdenum cutting machines are mainly used in electrical products, automotive components, military industry, etc. Water is utilized to control resistivity and other electrical properties. Due to the high-temperature discharge, the dielectric cleaning fluid removes the surface that melts and the particles that are cut [13].The research sequence was carried out on WEDM machine [14]. The selected criteria for the preparation of productivity were MRR and it can very well be represented (equation 1) as the ratio of the difference in weight during handling to the time and thickness of the composite [15]. Readings were recorded using the extended scale.

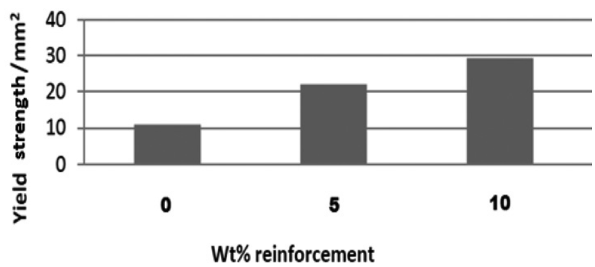

Fig. 5 Yield strength vs wt % of SiO_2
5. ábra Hajlítószilárdság SiO_2 tartalom függvényében

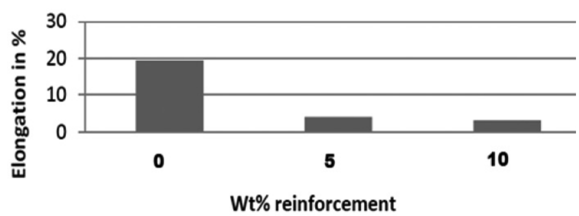

Fig. 6 Elongation vs wt % of SiO_2
6. ábra Megnyúlás SiO_2 tartalom függvényében

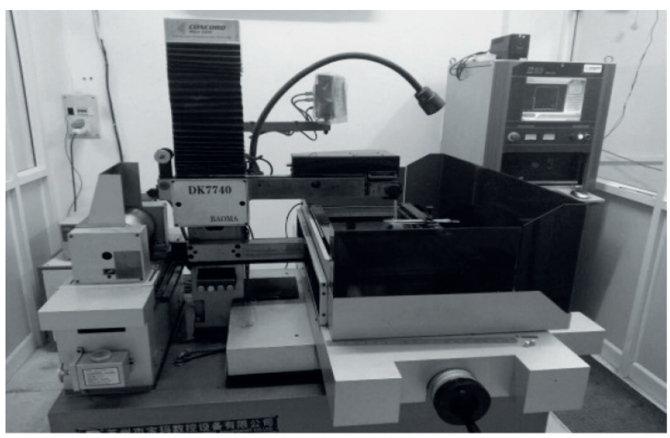

Fig. 7 Wire cut EDM machine
7. ábra Huzalos szikraforgácsoló gép

S.No	Item	Unit	DK7740
1	Travel of X/Y	mm	400 x 500
2	Table Size	mm	500 x 785
4	Maximum load of table	kg	500
5	Dimension (LxWxH)	mm	1700 x 1350 x 1700
6	Weight of machine	kg	2000
7	Best Finish	Ra≤µm	≤ 1.5

Table 2 Specifications of WEDM
2. táblázat WEDM eljárás műszaki adatai

$$MRR = (W_{ij}-W_{fj}) / (\rho_{composite} * t) \quad (1)$$

where W_{ij}&W_{fj} are the weights, t is the machining time.

To plan the experiments, Taguchi L9 orthogonal matrices were used. The Taguchi strategy is a procedure of value improvement, and this technique is utilized to lessen contrasts in item configuration and to improve quality. This strategy is known for its quality optimization [16]. Based on the trial configuration, tests were led, and the size of the chose piece was 10 mm. The test ought to be completed by changing the procedure parameters, which regularly influences the preparing procedure to get the required quality characteristics [17]. In this investigation, the Taguchi strategy is utilized to create orthogonal array (OA) for a sum of 3 parameters, namely pulse-on time,pulse-off time and current as shown in *Table 3*. The investigation expects to get a higher pace of material evacuation.In the present work, Analysis of Variance (ANOVA) was performed for a combined response variable using Minitab-19, statistical software and significant parameters responsible for the maximum MRR were listed in *Table 4*. It was found that the current has a significant effect (60.1%) on the MRR, followed by the pulse-off time (13%) and the pulse-on time (12%). The response data of the factor are presented in graphical form in *Fig. 8*. The best possible processing parameters are A1, B1 and C3. *Table 5* and *6* shows the reaction and ANOVA results respectively. By establishing the identified optimal values of the control parameters as input parameters (A1, B1 and C3), a control experiment is carried out using the same experimental setup and is repeated twice [18,19]. The values of the qualitative characteristics obtained during the verification experiments have an MRR of 16.1. The results of the validation tests are appeared in *Table 7*.

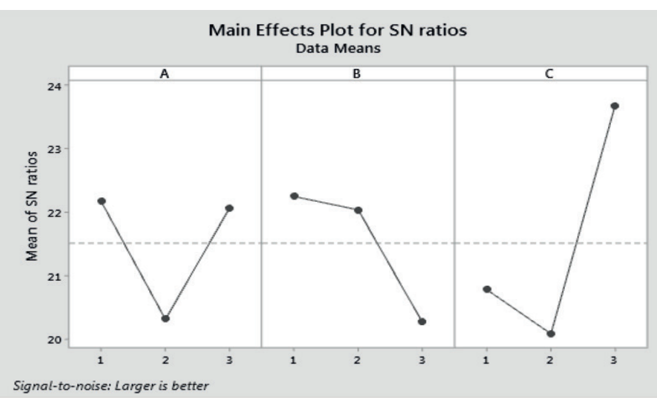

Fig. 8 Main effects plots for S/N ratios
8. ábra S/N arányok főbb hatásai

Parameters	Level-1	Level-2	Level-3
Pulse on time (µs)	6	7	8
Pulse off time (µs)	5	6	7
Current (A)	1	2	3

Table 3 Process parameters and their levels
3. táblázat Az eljárás paraméterei különböző szinteken

	Pulse on Time (µs)	Pulse off Time (µs)	Current (A)	MRR
1	6	5	1	13.9
2	6	6	2	9.99
3	6	7	3	15.2
4	7	5	2	10.2
5	7	6	3	15.3
6	7	7	1	7.13
7	8	5	3	15.3
8	8	6	1	13.2
9	8	7	2	10.1

Table 4 Experimental layout using L9 OA and performance result
4. táblázat Kísérleti elrendezések L9 OA felhasználása esetén és eredményeik

Level	A	B	C
1	22.16	22.24	20.78
2	20.31	22.03	20.08
3	22.06	20.26	23.67
Delta	1.85	1.98	3.59
Rank	3	2	1

Table 5 Response table for signal to noise ratios
5. táblázat Jel-zaj arányok válaszreakciós táblázata

Source	DF	Adj SS	Adj MS	F-Value	P-Value	%contribution
Pulse on time (µs)	2	8.624	4.312	0.90	0.526	12
Pulse off time (µs)	2	9.570	4.785	1.00	0.500	13
Current (A)	2	43.328	21.664	4.53	0.181	60.1
Error	2	9.557	4.779			
Total	8	71.079				

Table 6 Analysis of variance (ANOVA)
6. táblázat Varianciaanalízis (ANOVA)

S.No	Items	Initial cutting parameters	Optimal machining parameters	
			Prediction	Experiment
1	Level	A1B1C1	A1B1C3	A2B2C1
2	MRR	13.9	16.9	16.1
3	S/N ratio	22.8603	25.0557	24.1365

Table 7 Results of the confirmation test
7. táblázat Teszteredmények

4. Conclusion

Quartz sand waste discharged into the open area was collected and successfully used as reinforcement in a pure Aluminum matrix. In this study, a stir casting method was chosen for the manufacture of MMCs, as this is the cheapest manufacturing method used to make complex moulds. The mechanical properties of the newly manufactured Al / SiO_2 compounds improved significantly until the reinforcement level reached Al + 10% SiO_2. The hardness of pure Al was 26 BHN, increased to 30 BHN with the addition of 5% by weight of SiO_2 to the Al matrix and 33 BHN for 10% by weight of SiO_2. A rise in the hardness of 5 wt. % SiO_2 is 15%, and similarly for 10 wt. % SiO_2 is 26%. It was shown that the elastic limit of 5% by weight of SiO_2 showed an elastic limit of 100% higher. Similarly, for 10 wt. % SiO_2, the elastic limit is 28 N/mm^2, which provides an improvement of 154% compared with unreinforced Aluminum.The range of recovery results showed that a decrease of 4% for 5% by weight of SiO_2 and by 3.7% for 10% by weight of SiO_2.79% for a decrease of 5% by weight of SiO_2 and 80% reduction for 10% mass of SiO_2 with unreinforced Al.An optical microscope image shows that SiO_2 particles are well distributed in the Al matrix. It was concluded that Al with 10 wt. % SiO_2 can be considered as a suitable material in sectors where lightweight with improved mechanical properties is required. Therefore, Al + 10% by weight of SiO_2 obtained by casting with stirring are taken for Wire EDM cutting experiments.The current, which is the most significant parameter of 60.1%, gives a vital effect with a subsequent pulse-off time of 13% and the inclusion of a pulse on time of 12%. The percentage of errors (4.94) is in the acceptable range, which is less than 5%.

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