Material removal characteristics of Al-SiO₂ composite in WEDM

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 aluminium 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 aluminium MMCs have attracted throughout the world attention in virtue of their potentiality to replace massive equivalent, mostly in the automotive and energy area. Toughening of aluminium 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 research concentrates on the utilization of unused industrial waste and dispersing it in an aluminum matrix to produce composite by stir casting process [6]. The dissertation 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 particle 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. % SiO₂. 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. % SiO₂ 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 SiO₂ are proven in Table 1. The common particle size of SiO₂ 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    | SiO₂       |
| Mesh size           | 230        |
| Size                | 53 µm      |
| Thermal Properties  |   |
| Melting point       | 1760°C     |
| Boiling Point       | 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-SiO₂ 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-SiO₂.

Fig. 1  The casting of Al/SiO₂
1. ábra  Al/SiO₂ 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 / SiO₂ with the addition of 5% by mass of SiO₂, which shows an improvement of 185% compared to pure Al. Similarly, for 10 wt. % SiO₂, 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 SiO₂ will lead to greater cracking and consequently to lower tensile strength.

Fig. 2  Microstructure of AMC
2. ábra  AMC mikroszerkezete

Fig. 3  Tensile strength
3. ábra  Tárgyaló hosszúság
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% SiO₂. The hardness cost of pure Al turned into 26 BHN, which became elevated to 30 BHN with the addition of five wt.% SiO₂ within the Al matrix and 33 BHN for 10 wt.% SiO₂. Improvement of hardness value is achieved for 5 wt% SiO₂ is 15% and similarly, for 10 wt%, SiO₂ 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 SiO₂ 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% SiO₂ into Al matrix lead to low hardness. Fig. 4 demonstrates the hardness estimations of the ALMMC. Uniform distribution of SiO₂ into Aluminum matrix would increase hardness and also ductile Aluminum would become a little bit brittle.

The results confirms that 5 wt.% SiO₂ with aluminium composites gives the yield strength of 22 N/mm² which is 100% higher than yield strength of pure aluminium (11 N/mm²). Similarly, for 10 wt.% SiO₂, the yield strength is 28 N/mm², 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 SiO₂ in the aluminum lattice essentially improved the yield quality. Fig. 6 shows that at 5% by mass of SiO₂, a decrease of 5%, 5% by SiO₂ and 3.7% at 10% by mass of SiO₂ is observed, while at 5% by mass of SiO₂ and 10% by mass, a decrease in SiO₂ is achieved using unreinforced Aluminum reaches 80%. Because of warm confound, the Al grid enters the stress state, and SiO₂ particles enter the compression state. Since SiO₂ 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. % SiO₂ 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.
MRR = \( \frac{(W_{ij} - W_{fj})}{(\rho_{\text{composite}} \times t)} \)  \hspace{1cm} (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 chosen 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.
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\textsubscript{2} compounds improved significantly until the reinforcement level reached Al + 10% SiO\textsubscript{2}. The hardness of pure Al was 26 BHN, increased to 30 BHN with the addition of 5% by weight of SiO\textsubscript{2} to the Al matrix and 33 BHN for 10% by weight of SiO\textsubscript{2}. A rise in the hardness of 5 wt. % SiO\textsubscript{2} is 15%, and similarly for 10 wt. % SiO\textsubscript{2} is 26%. It was shown that the elastic limit of 5% by weight of SiO\textsubscript{2} showed an elastic limit of 100% higher. Similarly, for 10 wt. % SiO\textsubscript{2}, the elastic limit is 28 N/mm\textsuperscript{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\textsubscript{2} and by 3.7% for 10% by weight of SiO\textsubscript{2}, 79% for a decrease of 5% by weight of SiO\textsubscript{2} and 80% reduction for 10% mass of SiO\textsubscript{2} with unreinforced Al. An optical microscope image shows that SiO\textsubscript{2} particles are well distributed in the Al matrix. It was concluded that Al with 10 wt. % SiO\textsubscript{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\textsubscript{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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