Experimental investigation of electric discharge machining behaviour of TiC and graphite reinforced aluminium hybrid composites

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Abstract. In the current work, aluminum composites enhanced with graphite and titanium carbide (TiC) were fabricated using a liquid metallurgy route to guarantee uniform dispersion. TiC and graphite particles were added as reinforcements to the aluminum 6061 matrix. The EDM method was used to assess the machinability. Commercial EDM oil served as a dielectric, and copper served as the tool. Tool wear rate (TWR), material removal rate (MRR), and roughness (Ra) were observed in relation to essential parameters such as pulse off time, current, and pulse on time. The findings demonstrated that an increase in current and pulse-on duration raised MRR, it had a impact on surface quality. In addition to lowering TWR, graphite improved surface quality and acted as a solid lubricant, while TiC improved resistance to wear. Using SEM and common EDM features such craters, microcracks, and re-solidified layers, the surface morphology was examined. The research indicates that the machinability and surface quality of composites containing TiC and gr particles can be considerably improved.

1 Introduction

The need for materials with exceptional mechanical strength, thermal stability, wear resistance, and machinability has increased due to the rise of engineering applications. They bridge the performance gap between advanced ceramics and ordinary metals, MMCs have become an appropriate material. The intrinsic qualities of the aluminum, such as thermal conductivity, rust resistance, and light weight, have drawn a lot of attention to AMCs. These composites exhibit enhanced properties that make them suitable for high-performance applications in the aerospace, automotive, marine, and military industries when strengthened with the proper secondary phase materials, such as ceramics or solid lubricants [1-4].

By combining multiple reinforcement into a single matrix, hybrid metal matrix composites (HMMCs) provide more options for modifying its properties to satisfy technical specifications. By utilizing the matching effects of various reinforcing chemicals, hybrid reinforcement produces enhanced mechanical, tribological, and thermal qualities. When it comes to striking a balance between hardness, resistance to wear, and machinability, the combination of ceramic particles with lubricating components in an aluminum has shown

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encouraging results. TiC's exceptional firmness, resistance to wear and erosion, and exceptional thermic stability.

Strength and wear resistance of the composite are greatly increased when TiC is added to the aluminum. Conversely, graphite, a solid lubricant, has great thermal conductivity and good self-lubricating merits. Aluminum hybrid composites are difficult to process using traditional machining methods, despite their beneficial qualities. While the high thermal conductivity of aluminum may result in issues such built-up edges and dimensional errors. Presence of hard ceramic particles causes notable tool wear and poor surface quality [5-9].

These limitations have motivated the investigation of alternative machine methods capable of handling efficiently such advanced materials. One of the techniques is Electric Discharge Machining(EDM). EDM is not an obsolete on thermoelectric energy. In this process, significant removal occurs due to rapid localized melting and vaporization under the action of electric liberations amongst the specimen and the tool waterlogged in a dielectric. It is very effective for machining the electrical conductive and difficult-to-machine materials irrespective of hardness, brittleness, and toughness. Problems concerning tool wear and mechanical stress are greatly reduced [10-12]. This makes EDM very suitable for machining metal matrix composites and hence, AMC. The performance in EDM depends on several activity factors like discharge current, duration, potential difference, electrode material, and dielectric fluid. Out of all, discharge rate for electron flow and pulse interval are the most important aspects that control surface roughness (SR). In the case of composite materials, the nature and distribution of reinforcement phases further complicates the EDM process because their constituents respond differently under thermal energy [13-15]. This lack of understanding is the main motivation for the present investigation. The present research attempts to fill this gap by experimental investigations on the EDM with different ratios of TiC and Graphite. The primary aim is to explore the guidance of EDM factors on the most important act measure MRR during the EDM machining of these hybrid composites. For this, composites were prepared using stir casting, which is one of the well-known methods for preparing aluminium matrix composites. The method allows distribution uniformity and good bonding of reinforcements. In this case, aluminium 6061 alloy (Al6061) has been used as the matrix material due to its excellent combination of strength, corrosion resistance, and weldability. Composites including a constant 10% Graphite and different TiC (for instance, 5%, 10%, and 15% by weight) were fabricated.

2 Experimental information

2.1 Materials

This study refers to the fabrication of aluminium composites by numerous weight proportions of TiC and Graphite. The compositions selected for investigation include Al6061 + 5% TiC + 10% Graphite, Al6061 + 10% TiC + 10% Graphite, and Al6061+ 15% TiC + 10% Graphite. TiC was preferred for hardness and wear resistance, Graphite was included to improve the loosening characteristics.

2.2 Fabrication of composite specimen

The production of Al6061-based hybrid composites reinforced with 5%, 10%, and 15% Titanium Carbide along with 10% Graphite (Gr) particles measuring 50 microns was executed through the stir casting [Figure 1] method because of its ease and affordability. First, Al6061 alloy ingots were heated crucible with electric furnace and melted about 750°C. At the same time, the TiC and Graphite particles were preheated individually at about 300°C

for one hour to eliminate moisture and enhance wettability. As soon as the aluminium reached a completely molten condition, the preheated reinforcements were incorporated gradually into the melt. At the same time, a mechanical stirrer was employed to continuously mix the molten metal at 500 rpm for approximately 10 minutes, guaranteeing even distribution of the particulates within the matrix. A minor quantity of magnesium (approximately 1 wt%) was included to improve the adhesion between the matrix and reinforcements. The molten composite blend was subsequently poured into heated metal molds and permitted to cool in ambient conditions. After solidification, the castings were removed and subjected to machining and surface preparation for further analysis.

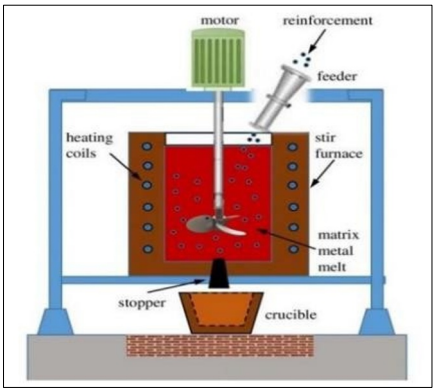

Fig. 1. Stir casting method.

2.3 Electric discharge machining

The wear test of composite specimens has been supported by Electric Discharge Machining (EDM), illustrated in Figure 2, is not an outdated machining method regularly engaged for precisely shaping hard and electrically conductive materials with exceptional accuracy. It operates created on the procedure of spark destruction, featuring regulated electric liberations happening at liquid like kerosene or deionized water, which melts and vaporizes small particles from the surface of the workpiece. The dielectric fluid aids in cooling the surface, removing debris, and preserving the spark gap. EDM eradicates the necessity for direct connection amongst the device and the piece, making it ideal for machining delicate or complex parts with intricate geometries and fine details EDM is utilized in the production of tools, medical device, and electronics sectors.

Fig. 2. Electric discharge machine.

3 Findings and analysis

3.1 Microscopic investigations

The presented SEM micrographs [Figure 3 a,b] refers the machined surfaces of Al6061 hybrid composites with Titanium Carbide (TiC) and Graphite particles after Electric Discharge Machining (EDM). The first image, at 500x magnification, shows a heterogeneous distribution of reinforcement particles, micro-voids, and re-solidified layers due to the extreme thermal effects during EDM. The second image, at 500x magnification, emphasizes micro-cracks, craters, and deposition of molten debris, which are typical of EDM owing to rapid cycles of heating and quenching. Presence of globules and micro-pores suggests localized material melting and vaporization. The third image shows a smoother surface with fine micro-cracks and melted zones, evidencing material erosion and surface re-casting. The formation of cracks is primarily because of the thermal stresses induced during sparking, while graphite's lubrication helps in eliminating debris.

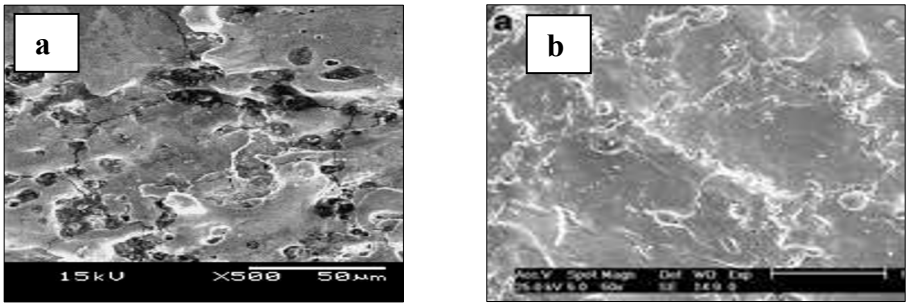

Fig. 3 (a, b). SEM images of Al6061 composites reinforced with TiC and graphite.

3.2 Hardness testing

Table.1 presents the composite density and Rockwell hardness (HRB) values for Al 6061 and its hybrid composites strengthened with changing percentages of titanium carbide (TiC) and constant 10% graphite. The base material, Al 6061, density of 2.701 g/cm³ and a hardness of 48.0 HRB. With the addition of 5% TiC and 10% graphite, the density slightly increases to 2.723 g/cm³, and hardness significantly improves to 65.1 HRB. As the TiC content is further increased to 10% and 15%, the densities rise to 2.745 g/cm³ and 2.812 g/cm³, respectively, while the hardness values escalate to 68.9 HRB and 75.1 HRB. This trend indicates that the incorporation of TiC enhances both density and hardness, primarily because of the hard particles.

Table 1. Density and hardness measurements of Al 6061 and its composites.

S.No	Specimen Composition	Composite material Density (g/cm^3)	Rockwell Hardness (HRB)
1	Al6061	2.701	48.0
2	Al 6061+5% TiC+10% Graphite Particles	2.723	65.1
3	Al 6061+10% TiC+10% Graphite Particles	2.745	68.9
4	Al 6061+15% TiC+10% Graphite Particles	2.812	75.1

3.3 EDM characteristics

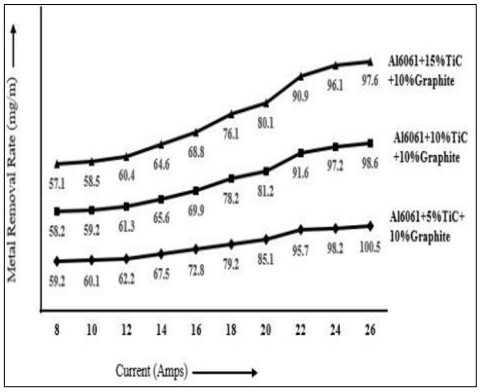

Fig. 4. Influence of current on metal removal rate.

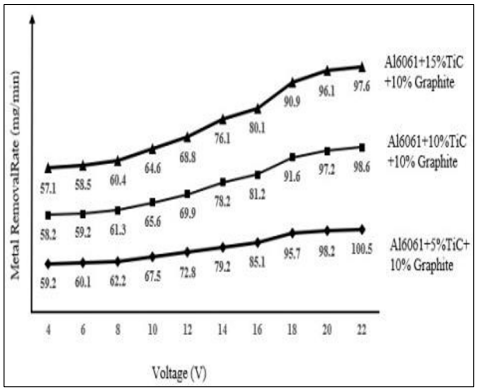

Fig. 5. Influence of voltage on metal removal rate.

Figure 4 refers changes in Metal Removal Rate (MRR) in relation to Al6061 composites with 10% Gr and different TiC proportions (5%, 10%, and 15%). It is noted that MRR improves by improving the speed of electron flows for all compositions. Among the three, Al6061 + 5% TiC + 10% Graphite exhibits the highest MRR at all current levels, reaching 100.5 mg/min at 25A. The composite with 10% TiC follows, attaining 98.6 mg/min, while the one with 15% TiC shows the lowest MRR of 97.6 mg/min at the same current. This trend indicates that while Graphite enhances electrical conductivity and lubrication, higher TiC content increases hardness but reduces conductivity, thereby lowering MRR. Hence, composites with lower TiC content facilitate better machining performance.

Figure 5 shows the variation of Metal Removal Rate (MRR) with applied voltage for hybrid composites reinforced with different percentages of TiC (5%, 10%, and 15%) and constant 10% graphite. As voltage increases from 4 V to 20 V, the MRR shows a consistent upward trend for all composite variants. Among them, the Al6061+5%TiC+10% Graphite composite exhibits the highest MRR values, reaching up to 100.5 mg/min at 20 V. The Al6061+10%TiC+10% Graphite composite shows intermediate MRR values, with a maximum of 98.6 mg/min. Conversely, the Al6061+15%TiC+10% Graphite composite records the lowest MRR, peaking at 97.6 mg/min. The trend indicates that increasing TiC content reduces MRR because of the higher hardness and low thermal conductivity of TiC, hinders effective material removal.

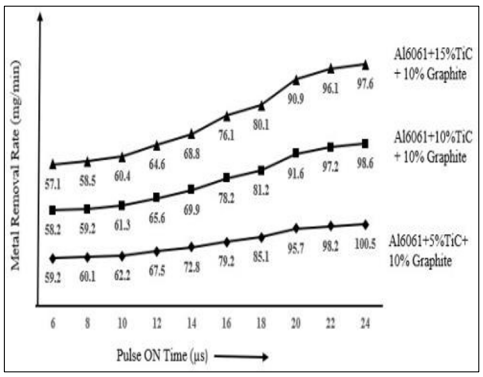

Fig. 6. Influence of pulse time on during metal elimination.

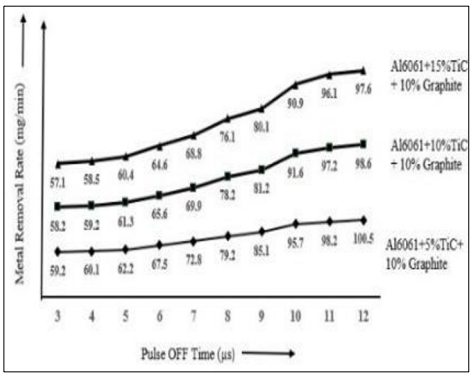

Fig. 7. Influence of pulse time off during metal elimination.

Figures 6 and 7 refer to the elimination of metals in Aluminium mixtures reinforced with TiC and graphite. Three compositions are compared: Al6061 with 5%, 10%, and 15% TiC, each with 10% graphite. As Pulse ON increases 6 to 24µs, MRR consistently rises for all compositions. Among the three, Al6061+15%TiC+10%Graphite exhibits the highest MRR, peaking at 97.6 mg/min at 24 µs, indicating superior machinability due to higher TiC content enhancing electrical conductivity and spark energy absorption. The combination Al6061+10%TiC+10%Graphite has the highest MRR of 98.6 mg/min, while the lowest MRR corresponds to Al6061+5%TiC+10%Graphite and reaches a value of 100.5 mg/min. From this trend, it could be understood that an increase in TiC improves MRR due to hardness and thermal conductivity of TiC, which supports faster erosion of the material.

4 Conclusion

It is apparent from the analysis that, while the machining parameters have influence, it is the composite make-up-particularly the TiC content-that has a greater influence on the MRR of Al6061. In general, the MRR increases with current, voltage, and pulse ON and OFF times because more spark energ. Al6061+5%TiC+10%Graphite continuously exhibits the highest MRR for higher current and voltage. However, in the case of Pulse off and on Time, MRR was observed to be enhanced for Al6061+15%TiC+10%Graphite, suggesting that with increased levels of TiC, material removal was greater at lengthened pulse duration, possibly due to increased spark absorption and thermal resistance. Overall, this study demonstrates that an ideal mix of mild TiC reinforcement results in EDM with the highest performance. Among the variants tested, Al6061+5%TiC+10%Graphite yields the highest overall MRR in conditions of normal current and voltage.

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