Fabrication and Mechanical Characterization of Rutile Reinforced Composite by using Wire Electrical Discharge Machining

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Abstract - In the present industrial sectors like aircraft, marine, bio-medical, chemical, etc., the usage of titanium has gained lot of interest due to its improved properties like strength, corrosion resistance, etc. Because of the improved properties like, higher hardness, toughness and poor thermal diffusivity make the material to fall under the category of hard-to-machine and this gave rise to the development and utilization of non - traditional machining processes. Machining of such components at a micro level have gained lot of attraction in the present industrial sector. There are many such machining processes used for machining micro and mini components. The accuracy and precision of components machined through such conventional processes are the challenging one. This gave rise to one of the non-traditional machining process called Wire electrical discharge turning (WEDT) process, which machines any electrically conductive cylindrical components of any shape and dimension. As a present research work, the process ability of WEDT process during machining of Ti-6Al-4V alloy using uncoated and diffusion annealed zinc coated brass wire is conducted. To conduct the experiments, a low cost rotary spindle setup is fabricated in-house. In order to predict the crater formation on the work material for the given input machining conditions, the numerical modelling is conducted using COMSOL Multiphysics 5.2 platform. A set of pilot experiments are conducted to validate the simulated results and found results are in agreement with each other, thus assuming the model to be correct to proceed further with the main experimentation. The samples machined with uncoated and diffusion annealed zinc coated brass wires are subjected to various mechanical and metallurgical studies to analyze the effect of WEDT process.

Keywords: *Turning, Zinc-coated, Optimization, Bio-corrosion, Characterization.*

1. INTRODUCTION

Advancement in electronic products keeps going on at a faster pace in every aspect. Remarkable reduction in size of electronic devices is, undoubtedly, one of the outcomes of this progression. But; the increased heat generation figures a major downside of the incessant innovation. Hence, there arises a pressing need for enhancing the cooling methodology to afford the processor base temperature in a convenient threshold range. It has been reported that conventional air-cooling techniques remain insufficient to meet such challenges [1]. In recent days, investigation into the concept of heat removal by liquids has attracted heightened interest among researchers in the area of materials science. Liquids function in heat removal process better than air due to their specific thermal characteristics. Research on this subject can be categorized in terms of the methods adopted. One of the methods is modification of the heat sink geometry in order to enhance surface area used with conventional fluid. Another method used is by altering the thermo physical properties of fluids used with plain geometry for maintaining proper functioning of electronic devices [2].

Recently, in an examination on the micro channel heat sinks, it was reported that by reducing the channel's hydraulic diameter, enhanced heat transfer possibility is attained. Further, a fluid carrying nanoparticles in basefluid has shown encouraging betterment for enhanced heat transfer applications. These fluids are known as "Nanofluids", which are a relatively advanced class offluids that consist of a base fluid with nano-sized particles (1–100 nm) suspended within them. These suspended particles are metal or metal oxide, which enhance conduction and convection coefficients, permitting enhanced heat transfer. Some distinctive nanofluids are ethylene glycol-based copper nanofluids and water-based copper oxide nanofluids [3].

Also, the fabrication of micro channel heat sinks for the transfer of heat flux requires considerable expertise. The smaller the electronic components are, the more complex its thermal management becomes. In such cases, surface roughness plays an principal role in pool and flow boiling in micro channels. Itis also noted that an increase in surface roughness brings about pressure dip and velocity variations in a single-phase flow. Hence, optimization of surface roughness coupled with other characteristics becomes significant. Not just the cooling techniques, and surface area as well as its roughness, but the convective heat transfer coefficient also depends upon the properties of base material of micro channel heat sink.

Some common materials used to make heat sinks are Aluminium alloys, Copper and Diamond. Aluminium heat sinks have often been found to be the natural choice to reduce cost, availability and better performance. Composite materials are also used in manufacturing heat sinks. These composites include a copper-tungsten pseudo alloy, Al/SiC (silicon carbide in the aluminium matrix), Dymalloy (Diamond in copper-silver alloy matrix), and E-Material (beryllium oxide in beryllium matrix). Being their thermal expansion coefficient matchingto ceramics and semiconductors, these materials are often used as substrates for chips [4].

2. LIERATURE REVIEW

Browers et al examined flow and heat transfer characteristics of aqueous Alumina nanofluid in micro channels. They found out an abetment in friction factor at lower Reynolds number and assumed that this might be due to higher particle concentrations. Majority of experiments revealed that larger pumping pressure with an increase in heat transfer. Hosseini et al proposed a research of heat transfer in micro channel heat sink assisted with magnetic field Al2O3/Water nanofluid. They analyzed the effects of Hartmann number, nanoparticles volume fraction and Nusselt number. The results have shown that Nusselt number has direct relationship with applied magnetic field. By using Al2O3/H2O nanofluid in wavy micro channels, Rostami et al proved that in three dimensional governing including continuity equations have three times higher heat transfer than conventional water based straight channels.

Sohel et al analysed the performance of mini channel heat sink using Al2O3/H2O nanofluid with volume fraction ranging from 0.10 to 0.25%. It was proved that there was an abetment of 0.18% heat transfer successfully. Mohammed et al analysed heat transfer of rectangular micro channel heat sink by varying Reynolds number. Alumina/water nanofluid with varying volume fractions between 1% and 5% used for conducting the experiment. It hasbeen found out that 5% of volume fraction has not any notable effect on heat transfer. Heat transfer could only be increased up to a particular volume fraction.

Akbari et al examined heat transfer by varying Reynolds number between 10000-60000 and volume fraction of CuO/H2O - based nanofluid with 0%, 2% and 4%. Turbulent flow through three-dimensional rectangular micro channels was scrutinized in this experiment. The result of the experiment has indicated that semi- attached rib in the micro channel increases heat transfer. Oliveria et al considered MWCNT particles dispersed in distilled water as nanofluid in a car radiator with varying nanoparticles concentration from 0.05% to 0.16%. For circulating air through radiator, a wind tunnel setup was used. Air flow rate was maintained at constant rate with varying hot fluid temperature. Thestudy has put forward a finding that there occurs only 5% decrease in heat transfer. It also shows that an increase in concentration does not have any effect in heat transfer.

2.1. RESEARCH GAP

Considering the literature review, research gaps identified have been depicted below:

- Though a good quantum of research has been carried out by researchers on flow and heat transfer in micro channels with restricted working fluids, geometrical patterns of the channels, difference in materials for micro channels, and operational constraints still implicate a major gap to be bridged.
- Machining of micro channels on Aluminium Metal Matrix Compositesfor heat sink application using atypical machining methods such as WEDM, Laser Machining and the influence of operational parameters on the machining characteristics has insufficient literatures.
- Confined literature has reported the utilization of natural resources as reinforcement in preparation of Particle reinforced Aluminium Metal Matrix Composites (AMCs) as a base material for heat sink/exchangersapplications.

2.2. OBJECTIVES

- To prepare Aluminium Metal Matrix Composites with Rutile as reinforcement and Aluminium Al6351 as matrix through powder metallurgy technique.
- To investigate the addition of Rutile on the physical, mechanical properties such as density, hardness, Compression strength.
- To machine the micro-channels on the fabricated composites using W- EDM machining.
- To optimize the process parameters to get near net shape using a hybrid approach grey-based Taguchi coupled with PCA.
- To investigate, report the flow and heat transfer behaviour of hybrid Al_2O_3/CuO/water nanofluid through the micro channel.

2.3. METHODOLOGY

The Figure 2.1 depicts the proposed methodology to the research work.

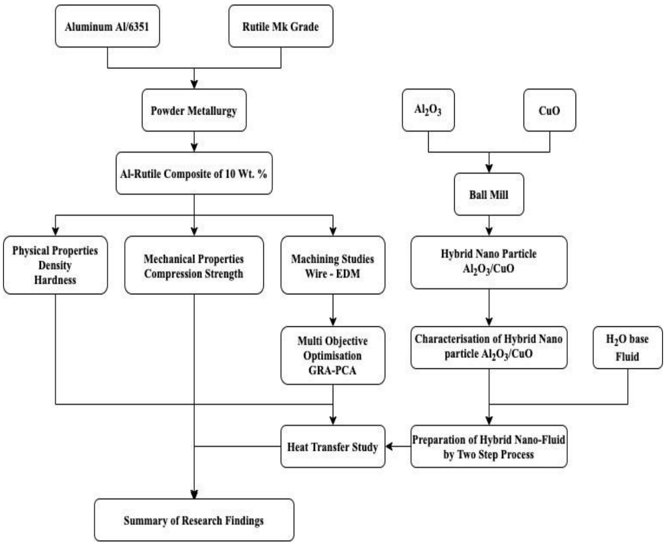

Figure 2.1 Proposed Methodology

3. MATERIALS AND METHODS

This chapter elucidates in detail; selection of matrix, reinforcement material, procedure followed to fabricate the composite material, micromachining of micro channel and the steps involved in optimization of machining parameter. Further, it explains the steps involved in the manufacturing of nanofluids and the heat transfer study.

Aluminium Alloy AA 6351powders, Rutile Mk grade mineral of 10 wt. % were weighed in digital balance and were blended in an attrition mill. The milling speed of 200 rpm is maintained and milling time considered is two hours with BCR of 10:1 is maintained to get uniform homogeneous mixture of powders. The die used for compaction is cleaned with acetone. The material is poured in to the die and compacting pressure applied at the rate of 250 MPa for 6 minutes under uniaxial load at room temperature. After compaction, the green compacts are ejected. Sintering is done in an argon atmosphere in a tubular type furnace. It is gradually heated up to 600°C below the melting point of AA6351 for three hours. Then the sintered composite is cooled and cleaned at atmosphere temperature. The Figure 3.1 depicts the setup for fabrication of composite. The fabricated specimen is of size Ø 30×15 mm in diameter.

a b

c

Figure 3.1 Powder Metallurgy fabrication setup and specimen

AA 6351/10% Rutile Mk grade was successfully fabricated by powder metallurgy route. Better quality of composite is ensured by porosity less than 5%. Uniform dispersion of particles ensured through SEM and EDS shows presence of titanium. Further machining study and application of heat transfer were discussed in detail.

4. FABRICATION OF MICRO CHANNELS USING WEDM

The prepared composite must be subjected to a secondary processing such as machining to obtain the near net shape of the product. In the current research, Wire Electrical Discharge Machining (WEDM) is employed to produce the micro channels. The machining operation is conducted by varying the electrical, no-electrical parameters. Thus the current, voltage and wire feed rate are considered as machining parameters and the output performance such as surface roughness, kerf width and depth are investigated.

4.1. EXPERIMENTAL RESULTS FOR WEDM

The fabricated AA 6351 – 10 wt. % Rutile composite was successfully machined using WEDM based on L27 array at different Current, Voltage and Wire Feed rate Conditions.

4.2. EFFECT OF MACHINING PARAMETERS ON SURFACE ROUGHNESS

Figure 4.1 presents influence of machining parameters on the surface roughness of the machined composites.

Since the pulse current and voltage increase, the machining rate increases with reference to wire feed rate and it results to improper finishing and shabby surface finish. Poor surface finish happens because of the presence of hardened reinforcement particles and they are hard to machine. While machining, the heat developed through spark generation melts the matrix material earlier than the reinforcement particles as it has a higher melting point than the base aluminum matrix; such happenings would possibly result in protrusion of these reinforced particles out of the base material and hence will definitely result in improper surface.

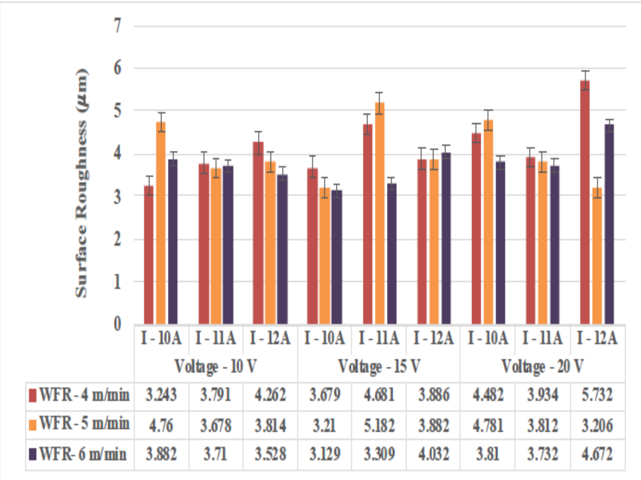

Figure 4.1 Effect of machining parameters on Ra

4.3. EFFECT OF MACHINING PARAMETERS ON KERF DEPTH ANDKERF WIDTH

The Kerf depth and Kerf width refer to the dimensional accuracy of the fabricated micro channel. Figures 4.2 and 4.3 depict the variations of Kerf depth and Kerf width in terms of machining parameters. When the current increases, the discharge of energy as spark in the wire electrode also increases. Consequently, more metal melting happens on the machined surface. High heat energy generated between wire electrodes and the composites produce a corner wear, which leads to a poor heat dissipation on the surface of the material. Thus, higher dimensional inaccuracy is produced and it results in increased Kerf depth and Kerf width.

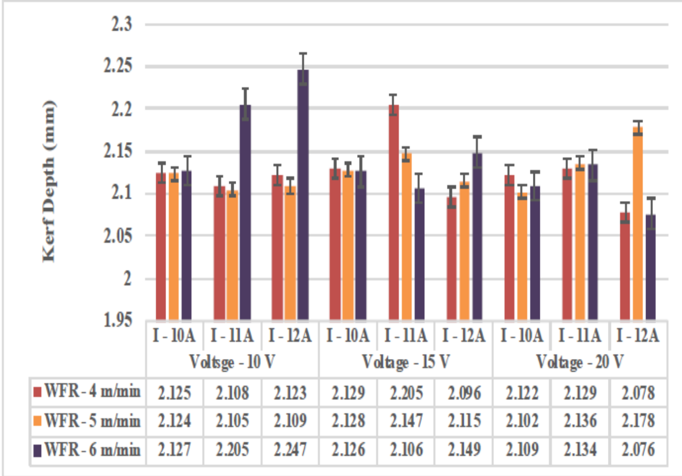

Figure 4.2. Effect of machining parameters on Kerf depth

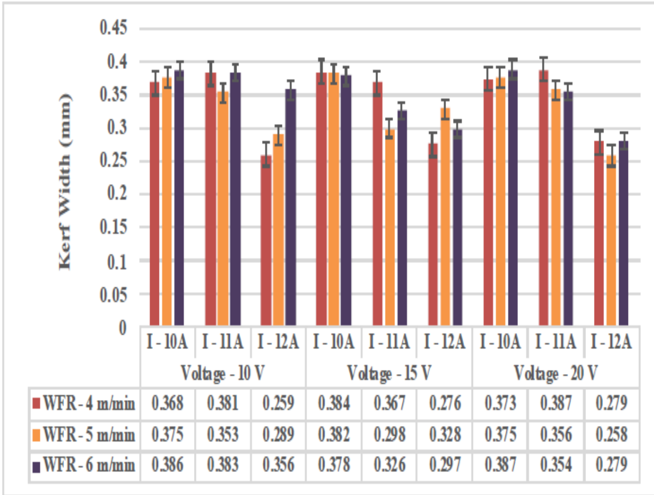

Figure 4.3 Effect of machining parameters on Kerf width

The experimental findings demonstrate that the micro channel in the AA6351 – 10 wt. % Rutile composite may be created utilising Wire Electrical Discharge Machining. The addition of hard reinforcing particles Rutile enhances machining resistance and increases surface roughness, Kerf Width, and Depth. However, the study's aim is to expand a composite that may be used in micro electrical device.

5. CONCLUSION

- Rutile reinforced composite has been successfully fabricated by powder metallurgy method and the micro channels are produced by using WEDM. Outcomes of the research work are:
- AA 6351/10 wt. % Rutile Mk grade has higher strength and excellent mechanical properties than the conventional alloys. The uniform distribution of reinforcement particles is verified.

- The formation of micro channel is feasible through WEDM at varying conditions and the surface morphology is examined through SEM and EDS.
- Minimization of kerf width, kerf depth and surface roughness has been established to get optimum results.
- The Current plays the major influence on affecting the combined objectives followed by wire feed rate and voltage.
- This hybrid technique has successfully optimized the WEDM process and the conformity test, which has been conducted, ensures the increment in GRG by 0.0025.
- The hybrid Al_2O_3-CuO/water nanofluid with different weight concentrations was successfully formulated using two-step process and utilized for the investigation and the following conclusions were made: Enhanced heat transfer is observed in hybrid nanofluid.
- The heat transfer rate was increased by 6% followed by the Reynolds Number from 3000 to 5000 and Nusselt number from 60 to 100 for the 0.3% of the composition when the mass flow rate increased. The similar pattern was absorbed for the 0.1 and 0.2 % of the composition of the nanofluids.
- Pumping power is spiraled with increased flow rate and concentration of nanoparticles but this hindrance can be overcome by the enhancement of heat transfer.
- It is observed that the heat transfer coefficient, mass flow rate and Nusselt number increase with the increase in Reynolds number.
- It is proved that, when the temperature average and pressure difference increase, Reynolds number increases gradually.

5.1. FUTURE SCOPE

- The prepared composite can be subjected to a non-destructive test.
- Vibration assisted and Cryogenic environment machining can beperformed.
- Numerical analysis of fluid flow and heat transfer characteristics of MWCNT-water nanofluid in rectangular micro channel heat sink can be performed.

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