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Parametric optimization of abrasive waterjet machining for aluminum 7075/boron carbide/zirconium silicate hybrid composites

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Abstract

In the present work, an attempt was made to study the machining characteristics of Hybrid Metal Matrix Composites (HMMCs) using Abrasive Waterjet Machining (AWJM). For preparing the composites, Aluminum alloy 7075 is cast with boron carbide (B_4C) and zirconium silicate ($ZrSiO_4$) reinforcement by the method of stir casting. Experimental investigation of the machining parameters on Depth of Cut (DoC), Material Removal Rate (MRR), and Surface Roughness (SR) was done. The independent parameters include Abrasive Mesh Size (AMS), Abrasive Flow Rate (AFR), Water Jet Pressure (WJP), and Traverse Rate (TR). The results of experiments reveal that low TRs increase SR, while short AMSs, high flow rates, and large WJPs increase DoC and MRR. Surface maps made by SEM exposed information about the surface texturing and the material removal processes. It was found that the optimal DoC was achieved at an AMS 80#, AMS of 340 g/min, WJP of 200 MPa, and TR of 60 mm/min for both unreinforced Al and the composite of Al + 5% B_4C + 5% $ZrSiO_4$. The results enable the development of proper AWJM procedures for HMMCs to ensure better surface finish and workability. From the experiments, it was observed that while smaller mesh sizes and greater AFR will improve MRR and DoC, it can at the same time have a negative effect on the overall performance of Kerf Taper angle (KT) and Surface Roughness (SR).

Keywords

Composite, machining, aluminum, boron carbide, zirconium silicate, abrasive mesh size

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Introduction

In the highly competitive industrial sector, depending on non-conventional manufacturing techniques is the only way to keep ever satisfying the ever-growing customer needs. The most innovative of these technologies is Abrasive Waterjet (AWJ) machining which is an accurate and versatile technology that has drawn significant interest because of the ability to apply it to a number of materials.[1–4] This research focuses on investigating the specific application of Abrasive Waterjet Machining (AWJM) with regards to Aluminum (Al) alloy, which is widely used in structural, automotive, as well as aerospace industries.[5,6] In most of the technical applications it is necessary to use the Al alloys because this material provides a special combination of characteristics such as high strength-to-weight ratio, high resistance to corrosion, as well as high ductility.[7,8] However, difficulties appear rather often when using traditional methods of machining because of some features of the Al—it is a soft and heat-sensitive material.[9] However, AWJM is a far better option available which is a non-thermal treating method, environmentally friendly, and does not cause any harm to the inherent property of the material. The investigation of the AWJM of Al alloy becomes relevant as industries maintain their strides towards a more efficient and productive means of working.

Al alloy 7075 involves the elements of Al, Zn, and Cu as the major alloying elements and small amounts of magnesium and chromium.[10] Sold material strength, corrosion, and ease of machining are therefore well managed in the makeup of the alloy. A solution heat treatment is often applied to Alloy 7075 and followed by quenching

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micro-cracks and possible abrasive particle embedment. The material removal process appears less efficient, with more mechanical wear and tear evident on the surface. The uneven surface and increased damage indicate sub-optimal process parameters, leading to lower MRR. Inconsistent abrasive flow or WJP may have resulted in less effective cutting and increased material resistance, contributing to the lower MRR observed. Smaller mesh sizes tend to result in better MRR and DoC, as seen in run 3 and run 9. Generally better MRR and DoC are linked with higher AFR, but KT and SR are observed with tradeoffs. However, SR and KT need to be optimized every time when WJP is higher and it will be positively connected with influence on MRR and DoC. For instance, while higher numbers of DoC and MRR equate to better performance, the same is associated with lower TRs, which advocates more total material inclusion.

From the machining of HMMCs with equal, higher, and lower percentages of reinforcement, it was found that there is a direct relation with the least KT angle with greater water pressure and minimum TR. A higher reinforcement percentage in the composites results in a better taper angle of the kerf because of high interaction between the abrasives and the reinforcement. Also, the fact that an elevated reinforcement percentage yields superior SR and MRR.[25]

Conclusion

In this investigation, various aspects of AWJM are focused, and their influence on the machining characteristics of HMMCs is summarized as follows: Based on the results of the experiment, the following conclusions arrived at:

- The values identified to reduce the tapered angle of the unreinforced Al are AMS: 120 # and AFR: 340 g/min, WJP 275 MPa and TR 90 mm/min.
- The superior parameters are found to be AMS 100#, AFR 340 g/min, WJP 125 MPa and TR 120 mm/min to avoid or minimize SR in unreinforced Al and Al + 5% B_4C + 5% $ZrSiO_4$. For Al + 10% B_4C + 5% $ZrSiO_4$, the optimal process parameters are identified as AMS 100#, AFR 240 g/min, WJP 200 MPa, and TR 60 mm/min.
- The optimal parameters for achieving the highest MRR in AWJM are also identified for both the basic and reinforced composite materials. The highest MRR is achieved using finer AMS (80#), higher AFRs (440 g/min), moderate WJP (200 MPa), and low TRs (60–90 mm/min). Unreinforced Al exhibits the highest MRR, followed by composites with 5% B_4C + 5% $ZrSiO_4$, and lastly composites with 10% B_4C + 5% $ZrSiO_4$.
- A comparison of SEM analysis indicated rhythmic variations in the surface morphology of machined material which implies that there are different material removal processes based on cutting conditions. The outcomes of the study provide important recommendations regarding aspects of AWJM parameters that influence the achievement of preferred machining qualities, enabling the improvement of the process applicability across industries.
- From the SEM examination, variations in the material removal kinetics and the altered surface morphology were depicted. The recommendations made by the current study are general for modifying the AWJM parameters to produce the needed machining properties that will enhance the process suitability to the industrial sector.
- Runs 3 and 9 observed with better MRR and DoC due to lesser mesh size, since it has lesser area. Even though they prove to reduce KT and SR, higher AFRs increase MRR and DoC at the same time. An increased WJP exerts a positive influence on both MRR as well as DoC, however, demands an optimal balance of the controlling SR and KT parameters. The analysis indicates that higher DoC and MRR correlation typically results in lower TRs suggesting the nature of material interaction.

The conclusions made in the study provide significant new data about the specifics of AWJM usage within the industry, pursuing enhanced surface finish and operability in the manufacturing of advanced composite materials. While the paper has addressed the parameter optimization required for the machining of Al-based HMMC, there is a great scope for research on the extent to which the porosity and other defects in the composites affect the material performance and machinability.

Authors' contribution

P. Thamizhvalavan contributed to writing–original draft. M. Varatharajulu contributed to conceptualization and methodology. Jagadeesh Baskaran contributed to writing–review and editing.

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Supplemental material

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