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# Surface integrity in tangential turning of hybrid MMC A359/$B_4C$/$Al_2O_3$ by abrasive waterjet

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ABSTRACT

This paper deals with the abrasive waterjet turning of newly developed hybrid MMC A359/$B_4C$/$Al_2O_3$ produced by electromagnetic stir casting. The justification of the fabrication was revealed by microstructural images and x-ray diffraction results. The main aim of the study is to analyse the machining behaviour of produced hybrid MMC under abrasive waterjet turning. The surfaces created at different traverse speed were discussed in terms of surface integrity and surface texture. Optical profilometer was used to generate surface roughness report and 3D visualization of the machined surface. Olympus LEXT OLS 3100 laser confocal microscope was used to collect 2D and 3D surface topographical details of the machined surface. Surface morphology was discussed by FE-SEM images to evaluate surface defects. Residual stresses and microhardness test through the depth profile were also carried out to analyse the machined surface and subsurface. It has been found a perfectly round, slightly undulated surface which shows ploughing nature. The results also reveal the higher rate of material removal with rough cutting.



## 1. Introduction

The novelty of new class of economical materials and continuous demand for functionally upgraded materials for various specific applications leads to the growth of MMCs [1]. MMCs plays a vital role to meet such requirement because of their enhanced properties like light weight, upgraded mechanical and thermal properties compared to other manufacturing materials [1,2]. MMCs are basically the homogeneous phase of two distinct materials one is a metallic phase of matrix and other is a non-metallic phase of reinforcement which is dispersed throughout the matrix of metallic phase [3]. Reinforcements are added in the precise fraction to meet particular properties for specific applications. However, adding more than one type of reinforcement makes hybrid MMCs, which overcome the negative aspects of single reinforcement or to keep any previous property of the matrix material [4]. Among the available type of MMCs, aluminium MMCs is preferable over other due to its excellent properties [4].

The presence of hard abrasive (ceramic) particles creates significant tool wear and reduced surface quality, which leads to non-acceptability of MMCs [5]. The non conventional machining of these materials provides the better results of machining performances compared to conventional machining [5,6]. Some common types of non-traditional machining methods like electric discharge machining (EDM) [6,7], abrasive waterjet (AWJ) cutting [6,8], electro-chemical machining (ECM), plasma arc cutting etc proves their suitability to such MMCs due to remarkable properties like free from hardness and strength of the material as well as less responsive to the type of material [6].

The present work deals with the study of behaviour of hybrid MMCs under abrasive waterjet turning (AWJ turning) process. The experimental study of machining results as well as surface qualities has been examined. The impinging of high speed abrasive waterjet

*Abbreviations:* $a_p$, actual depth of cut (mm); AWJT, abrasive water jet turning; d, workpiece diameter (mm); $d_f$, focusing tube diameter (mm); $d_o$, orifice diameter (mm); FE-SEM, field emission scanning electron microscopy; $l_f$, focusing tube length (mm); MMC, metal matrix composite; n, rotational speed (rpm); p, water pressure (MPa); Ra, Rq, Rz, surface roughness parameters (μm); z, stand-off distance (mm); $m_a$, abrasive mass flow rate (g/min); MESH, particle-size distribution; EDM, electric discharge machining.

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on the workpiece surface erodes the material by means of plastic deformation, and turning surfaces seem like ploughing nature. The significant parameters of the AWJ turning process like abrasive mass flow rate ($m_a$) and water pressure (p), stand-off distance (z), type of abrasive, abrasive size ($d_f$) and traverse speed of nozzle (v) are reported in past studies which can greatly affects the machining results [6,8]. The parameters such as rotational speed (n) of workpiece can also be considered as significant process parameters in case of turning process. The main advantage of the AWJ process as opposes to the other non-conventional techniques is that it can produces the machined surfaces without melting, wrapping or distorting it and can be applicable for any type of material without the use of any thermal effect and negligible cutting forces [6]. However, by adding the additional degree of freedom in the rotational direction, it can be applicable for the disintegration of rotating a workpiece during turning operation [9].

The effect of machining parameters on the machining outcomes can be evaluated to verify the output responses and surface quality. The quality of the machined surface is characterised by its roughness value, which highly influences the fatigue life, creep, dimensional accuracy and quality of the product. The integrity of machined surface is also one of the key criteria to find a machined surface free from defects like crack initiation, tearing of surface, brittle fracture of surface particles, recrystallization, phase transformation, plastic deformation and microstructural changes. Due to the plastic deformation and minimal work hardening of machining surface, the residual stresses are developing in its sub-surfaces, [10] whereas, AWJ process if free heat affected zone and microstructural changes which leads to the nominal variation of micro-hardness in the depth below the machined surface [11]. The AWJ has been applied for different materials including metal alloys [12], Nanocomposite [13], MMC [4] and even rocks [14]. In addition to material disintegration application, the process can also be used for surface treatment like peening operation [15].

The conventional AWJ machine can be modified and also be used for turning like operations. Many researchers have reported successful experiment using AWJ turning. Some of the significant works are mentioned here. Manu and Babu [16] studied the influence of impact angle during turning of aluminium alloys. The experimental results suggested that normal impact angle should be used for rough turning and low impact angle for smooth operations. Manu and Babu [17] further attempted to model the turning process for a ductile material. The proposed model was successful in predicting the final diameter of the specimen after AWJ turning operation with variable traverse speed, impact angle and nozzle diameter. Axinte et al. [18] showed the application of AWJ turning to profile of grinding wheels. They observed that the proposed method roughed and semi-finished grinding wheels in significantly lower time with respect to the traditional dressers. Thomas DJ [19] studied the surface properties and internal transformation changes induced during abrasive waterjet cutting process. He concluded that traverse speed plays an important role on surface roughness and cut edge hardening. The variation in traverse speed to predict the final diameter in terms of mathematical model was developed by Zohoukari and Zohoor [20]. The results obtained were more accurate than achieved by Manu's model [16]. Uhlmann et al. [21] compared AWJ turning with traditional turning method on ϒ-TiAl alloys and observed that area affected and hardness penetration by AWJ turning is lower as compared to traditional turning. Li et al. [22] studied AWJ turning on AISI4340 tensile steel and concluded that turning at normal impact angle with faster surface speed, results in significant material removal rate. Li et al. [23] further suggested a mathematical model for determining the depth of cut to predict accurately with a very low error value. Hloch S and Ruggiero A [24] did online monitoring of the cutting process to detect the defects caused during the process, fracture of focusing tube and detection of orifice damage during pulsating waterjet. Ali et al. [25] did a visualization study of AWJ turning for alumina ceramics. They observed that cutting parameter like water pressure, traverse speed significantly influenced the depth of cut and change in impact. Liu et al. [26] studied radial mode and offset mode turning for alumina ceramics and observed the effect of stand-off distance on machining performances. The results showed that radial mode should be associated with rough turning operation whereas offset mode with fine turning. Li et al. [27] suggested a mathematical model of surface roughness for turning of high tensile steels. They assumed traverse speed, nozzle tilt angle, abrasive mass flow rate, surface speed and water pressure as variables and found out that the proposed model showed the accurate result with a low average error. Yue et al. [28] optimised machining parameters in turning alumina ceramic using response surface methodology (RSM) technique. The results showed that MRR was principally influenced by water pressure and at an optimum setting of parameters larger rate of material removal at smooth finishing was achieved. Hlavacek P et al. [29] investigated the effect of traverse speed, rotational speed and direction of rotation on the surface quality of sandstone workpiece with AWJ turning. Their result revealed that direction of rotation of workpiece influenced the final surface quality. Zhong and Han [30] examined the surface quality during turning of glass rod. It was concluded that a rough cutting with larger MRR was obtained while machining with AWJ turning as compared with other processes. Jan carach et al. [8] investigated the role of traverse speed on the machined surface while turning Incoloy alloy 925. They concluded the increasing trend in surface roughness while increasing the traverse speed. Jan carach et al. [9] further investigated the effect of a technological and abrasive factor on the surface quality of Monel K-500 alloy. The results showed that roughness and MRR were influenced by abrasive mass flow rate and traverse speed whereas the size of particles did not show any significant influence on the output. The surface roughness can be measured both offline and online. Hreha P. et al. [31] carried surface roughness measurement using online monitoring of vibration caused due to interaction of abrasive water jet with the workpiece surface. The above aforementioned authors delivered knowledge about the cutting mechanism and surface quality of metals by AWJ turning process. They found AWJ turning an effective technique which can be applied to any type of material. Several mathematical models have been derived to show the relationship between process parameters and surface roughness profile parameters, MRR and hardness. In addition to the study of influence of process parameters on workpiece oriented output parameters, Hreha P et al. [32] further studied the wear of focusing tube that occurs during AWJ machining using vibrations as source of information. They also studied the influence of machining parameters on nozzle wear rate. Mainly investigated materials were steels, steel alloys and titanium etc. However, some of the work has been found in medical industries like in bone disintegration [33] and sand stone turning [29]. Due to constantly developing new materials with specific mechanical properties in manufacturing industries leads to the continuous improvement in AWJ process which allows the precise surface finishing and improved surface quality. Here an attempt is made to develop a new class of aluminium hybrid MMC and evaluate its machining behaviour under AWJ turning.

The present work highlights the newly developed cylindrical hybrid MMC of $A359/Al_2O_3/B_4C$ produced by electromagnetic stir casting route. The authenticity of the fabrication process and development of hybrid MMC was justified by microstructural images, energy dispersive x-ray spectroscopy (EDS) and x-ray diffraction (XRD) test. Further, it deals with AWJ turning of the produced hybrid MMC cylindrical workpiece and analyses the surface integrity at three different levels of traverse speed of nozzle while keeping other parameters were constant. The percentage reduc-