Vol. 03, Iss. 2 (2025) 229-236, DOI: 10.61552/JME.2025.02.007

Journal of Materials and Engineering

www.jme.aspur.rs

Research article

Investigation of Solid Lubrication and Its Tribological Performance in Turning of MWCT Embedded Al-MMC

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Keywords:

Turning process
MMC
Texture
Solid lubrication
Supply

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Received: 10 June 2024
Revised: 11 July 2024
Accepted: 14 August 2024

A B S T R A C T

The intensive application of cutting is crucial in the process of machining performance for removing heat generated during metal cutting. At the same time, it generates issues related to environmental as well as operator heat. The selection of an alternative cutting condition and its performance analysis are an important task. Two different techniques employed in solid lubrication includes in this work, namely manual filling and supply using devices. Multi walled Carbon Nano Tube (CNT) embedded Aluminum based Metal Matrix Composite (Al-MMC) is used as work piece. The texture on the rake face of the cutting tool inserts serves a purpose in solid lubrication. Electromagnetic stir casting is used for composite preparation and Electrical Discharge Drilling (EDD) was used for texture preparation. Experiments are executed with the help of Taguchi design of experiments. The findings that indicated the solid lubrication performance is comparatively better with device supply mode than manual mode of supply. Supply of slid lubrication using device is noticed that better surface quality due to continuous storage and uniform supply. This Study intends to explore the issues associated with enhancing the distribution of solid lubricant to the area where cutting occurs in order to increase performance and efficiency of near dry machining.

1. INTRODUCTION

Composite materials are widely preferred in various engineering application. MMC is a type of composite materials which contain of hard metal matrix and reinforced particles. This combination plays a vital role in load carry capacity. Also, exhibits superior mechanical qualities and may be formed into near net form. Due to these attractive advantages, it is widely used in aerospace and automobile sectors [1-3]. Machining of MMC is a difficult one because of hard reinforcement are presented. Cutting tool, condition and coolants are acting an important role for machinability enhancement. Tribological condition is influenced with this reason. In general, A cutting fluid or a coolant based on hydrocarbon oil that is used in machining. It causes environmental problems. To avoid this issue, researches are attempted different alternative cutting conditions. One of the various cutting conditions is textured cutting inserts packed with solid lubricant. [4, 5]. Texturing on cutting tool inserts is used to fill the solid lubricant To minimise early tool failure during the dry machining process, hard coatings were applied to cutting tools, and the coated TiN tools were used to explore the machining of Ti-6Al-4V [6-8]. Textures serve as a storage tank. It retains solid lubricants and generates thin lubrication film when gets thermal expansion due to plastic deformation and heat generation There are number of solid lubricants are available in which WS_2 solid lubricants are widely used due to its excellent properties, lubrication nature and less frictional effect. There is an issue due to solid lubrication filling and supply while machining. [9] conducted a machining performance study using textured cutting inserts and solid lubrication. A Laser was employed to generate a minuscule aperture on the surface of the rake, which was subsequently filled with a compacted lubricating substance. LASER was used to make a micro hole on the rake face, and the groove was filled with solid lubricant. The result observed that enhanced machining performance in terms of frictional fierce reduction and tool-chip length. Song et al. [10] used graphite filled textured cutting inserts for turning process A tiny hole was created on the rake side of the cutting inserts using micro EDM. The result revealed that machining zone temperature and wear of the cutting inserts were reduced. Also, pointed out solid lubricant film was formed and reduced frictional effect with solid lubricant. Krishna et al. [11] investigated the functionality of solid lubrication in the turning process was examined. The performance of a nano boric solid lubricant was studied. A device was developed for supplying solid lubricants to the cutting zone. The results demonstrated that solid lubrication improved machining performance. [12] investigated about particle size variation study of solid lubricant. In their work, a device was prepared for the applying of solid lubrication in the cutting zone. The result was noticed that machining performance was enhanced. Bushan et al. [13] conduced a machinability study on AL-MMC and optimized the process parameters using response surface methodology Changing the process parameters, optimized the machining forces. The results showed that utilising optimized settings, machining forces were decreased. Arul Kirubakaran et al. [14] used textured cutting insert on Al-MMC for machinability investigation. Three different patterns of textured inserts were used. The result was showed that pattern of texture was influenced machining performance effectively Devaraj et al. [15] investigated the machinability of Al-MMC utilising textured cutting inserts. The specifications of textured cutting inserts were adjusted and their performance was studied. The findings demonstrated that textural parameters had a substantial impact on machining performance.

From the past studies, it is realized that petroleum derived cutting fluids are generated environmental related issues. It is realized that a strong requirement in the field of alternative cutting condition. Texture introduced on rake face and application of solid lubrication is playing an alternative cutting condition. Most of the literatures are not concentrated about the supply of solid lubricant. Few literatures are used manual application of solid lubricant and few literatures are used a device for application of solid lubricant It is recognised that the delivery of solid lubricant to the machining zone must be thoroughly investigated. In this work, a comparison study is carried out about supply of solid lubricant while turning of Aluminium based MMC.

2. MATERIALS AND METHODS

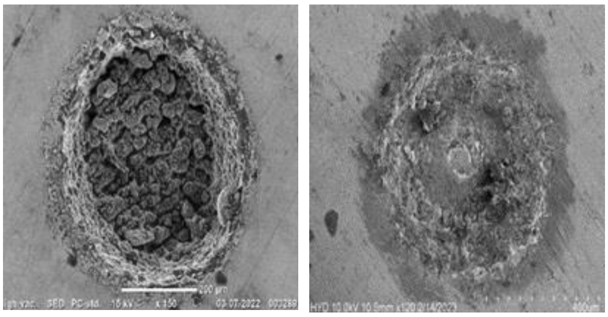
Al-MMC can be prepared using stir casting route. In general, mechanical stir type casting route is preferred. But few limitations in terms of defect on produced Al-MMC. Hence electromagnetic stir casting is used to develop Al-MMC. It has few advantages in terms of stirring action. In electromagnetic stir casting process, electromagnetic effect and stir current effort are played an important role. Liquid metal flow can be controlled using electromagnetic field. Due to presence of magnetic field, Lorentz force (force per unit volume) influences the electromagnetic force and better stirring action is achieved and will be useful to obtain defect free composite. Two main parts of Al-MMC are matrix and reinforcement. Al 6061 alloy used as matrix and Silicon Carbide (SiC) with MWCNT nano particles are reinforcement. Figure 1 Electromagnetic stir casting setup. The cylindrical rod produced with the diameter 45 mm. Tungsten carbide with plain grade is used as cutting tool inserts. Electric Discharge Drilling (EDD) is used to introduce micro hole for filling of solid lubricant. Figure 2 shows the Electric Discharge Drilling setup. In general, LASER is used to introduce micro hole on cutting tool inserts. EDD has few advantages in terms of minimum heat affected zone and better dimension stability than LASER source. Figure 3 a-b shows the SEM images micro hole from EDD and LASER. Tungsten disulfide (WS_2) is used for solid lubrication purpose. In this work, two different approaches are attempted. First one is manual filling of solid lubricant and second one device for supply of solid lubricant. Table: 1 and 2 presents composition used for preparation of Al-MMC and levels used for control factors. Experiments are carried out utilising a CNC turning centre and a Taguchi L_9 orthogonal array. Experiments are carried out utilising a CNC turning centre and a Taguchi L_9 orthogonal array.

Table 1. Al SiC MWCNT material composition.

Sl.No	Material	Weight %
1	Magnesium	1%
2	Silicon	16%
3	MWCNT	1%
4	Aluminium	Remaining

Fig. 1. Electro Magnetic stir casting setup.

Fig. 2. Electric Discharge Drilling.



(a) micro hole using EDD (b) micro hole using LASER

Fig. 3. a,b shows the SEM images micro hole from EDD and LASER.

Fig. 4. CNC Machine with solid lubrication Device and Cutting inserts with micro-hole.

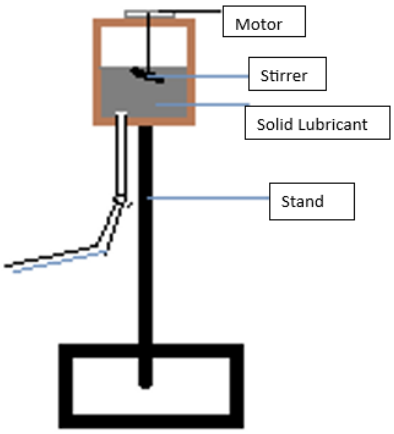


Fig. 5. Solid Lubrication Device supply.

As previously stated, two techniques are available: manual filling and device supply. SAE 40 oil is used to combine the ingredients and create a semi-solid paste. This is used on textured cutting inserts with tiny holes. Figure 4 shows CNC Machine with solid lubrication device and Cutting inserts with micro-hole. In the second method, solid lubricant powder is combined with SAE 40 oil in an 80:20 weight ratio. A device is used for supplying solid lubrication at the cutting zone is created. Figure 5 shows solid lubrication device supply. A surface roughness tester is used to determine the surface roughness of a machined region. It is measured using the ISO 4287:1997 standard with a cut-off length of 0.8 mm and a sampling length of 5 mm. For examination, the surfaces average roughness measurement is considered. Average measurement of roughness of the surface is taken into account. It is created by combining the first and second halves of the machined work piece length. It is used to determine the efficacy of solid lubrication. Table 3 displays the investigation's findings.

Table 2. Sample parameters.

Sl. no.	Cutting speed (m/min)	Feed(mm/rev)	Depth of cut (mm)
1	73	0.08	0.3
2	104	0.12	0.6
3	135	0.16	0.9

Machined sample surface roughness is measured using SJ-210 surface roughness tester. The measurements are carried out three times and the average values are considered for further analysis. Arithmetical average surface roughness (Ra) is an important machinability characteristic. The parameter (Ra) is an indication of machinability, which is the area between the roughness profile and its centre line during the measurements. These Ra measurements re measured using ISO 4287:1997 with a cut-off length of 0.8 mm and sampling length of 5 mm.

3. METHODOLOGY

Using an orthogonal array, a S/N ratio, and an ANOVA analysis is the Taguchi technique. A statistical technique called an orthogonal array is used to construct trials with fewer tests, in less time, and at a lower cost. It is also used to see how different process elements affect how people respond. The Signal to Noice ratio (S/N ratio) is a metric that may be employed to evaluate the disparity between the measured value and true value. The Taguchi technique cannot be used to determine the influence of process factors with percentage contributions on the answers; hence ANOVA is the optimum approach. Figure 6 shows the methodology for calculating optimum level parameters.

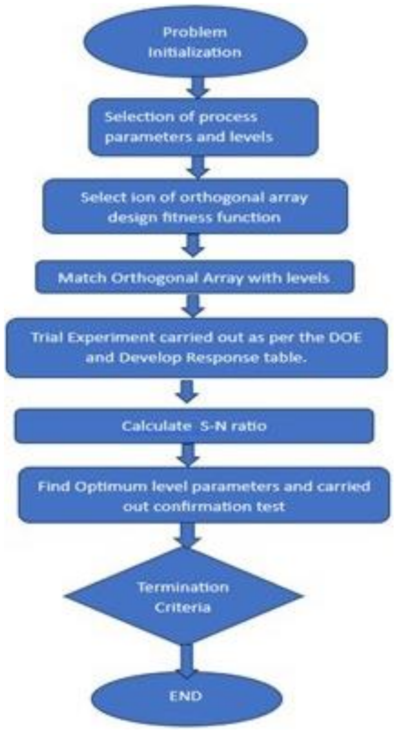


Fig. 6. Methodology for calculating optimum level parameters.

Table 3. Shows the experimental results.

S.no	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Surface roughness in µm	
				Solid lubricant manual supply	Solid lubricant device supply
1	73	0.08	0.3	2.22	1.67
2	73	0.12	0.6	2.44	1.88
3	73	0.16	0.9	2.62	1.98
4	104	0.08	0.6	1.94	1.59
5	104	0.12	0.9	2.18	1.74
6	104	0.16	0.3	2.49	1.82
7	135	0.08	0.9	1.54	1.46
8	135	0.12	0.3	1.96	1.77
9	135	0.16	0.6	2.35	1.98

4. RESULTS AND DISCUSIIONS

In this work, a comparison study about the application of solid lubricant to the cutting region is investigated during turning of Al-MMC. Surface roughness of the machined area is considered as machinability indicator and the results are interpreted using main effect plot. To determine the importance of an input parameter's impact on a response, ANOVA was employed. Textured cutting inserts with solid lubrication are termed as self-lubricating tool which act as alternative cutting condition. Texturing on rake face is used to act as solid lubricant storage. During metal cutting or plastic deformation, solid lubricants is formed a thin lubrication film around the cutting zone due to heat generation [16]. Solid lubricants are powder form in initial and soft in nature.

Tungsten disulfide was used as solid lubricant which has significant properties such as hexagonal structure, less frictional co-efficient, minimum shear strength and brittle in nature. Due to these advantages, it is get smeared easily and generates thin lubrication film. The film formation is due to squeezing and dragging of solid lubricant while metal cutting. Direction of chip produced during metal cutting is influenced by the texture was added to the cutting inserts' rake face. The combined advantage of solid lubricants and texturing, reduced frictional effect and better surface quality are achieved. In general, chip flow direction is not predictable during metal cutting. Texturing with micro hole pattern has significant advantages in terms of direction dependent. Few other types of texturing pattern are available such as parallel and perpendicular [17,18].

As was previously indicated, it is challenging to feed solid lubrication to the cutting zone. The provision of solid lubrication to the cutting region is not generally noted in the literature. In this work, major objective is to analyze and compare the supply of solid lubricant to the cutting zone. Figure 7 and 8a-b represents the surface roughness variation with different mode of solid lubricant supply and its main effect plot. The findings of a comparative analysis suggest that solid lubricant supply using appropriate device is performed better machining performance than manual filling method. The observations from the results are manually filled solid lubrication on textured cutting inserts are behave uncoated inserts at starting condition. Cutting zone temperature increases gradually, thermal expansion of solid lubricant and form a thin layer. In case of supply using device generate thin lubrication film around the cutting zone immediately. It is acknowledged that constant thin lubricating film is obtained throughout the experiments when compared to manually fill solid lubricant supply. Along every step of the machining process, the measurement for average surface roughness is separated into two separate half positions.. First half of the machined area is shown higher surface roughness and second half is shown lesser average surface roughness with manually filled solid lubricant. In case of solid lubricant supply using device, reduced surface roughness over the whole length of the machined piece, as well as less than manually poured solid lubricant. It's possible that the cutting zone is receiving a steady and homogeneous supply of solid lubricant.

Taguchi technique determines the effect of individual parameters for entire process using ANOVA. The ANOVA table contains the degrees of freedom (DOF), sum of squares (SS), mean square (MS) and percentage contribution (P) of input process parameters. The significant effects for controlling the responses, contribution of the parameters in terms of their percentage error and variance in the process are determined by ANOVA [19,20]. The result of ANOVA of the surface roughness is shown in Table 4 and 5. It is observed that from all solid lubrication conditions, feed rate has highest contribution.

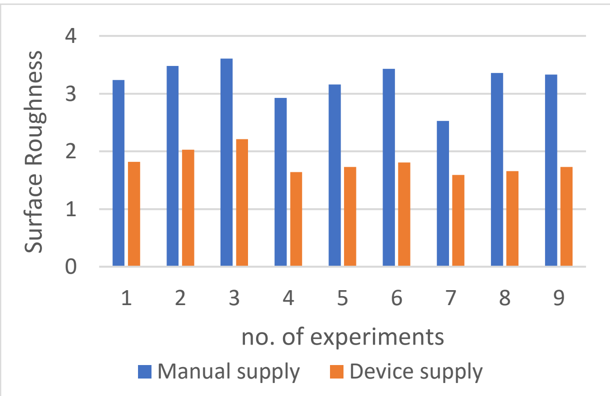
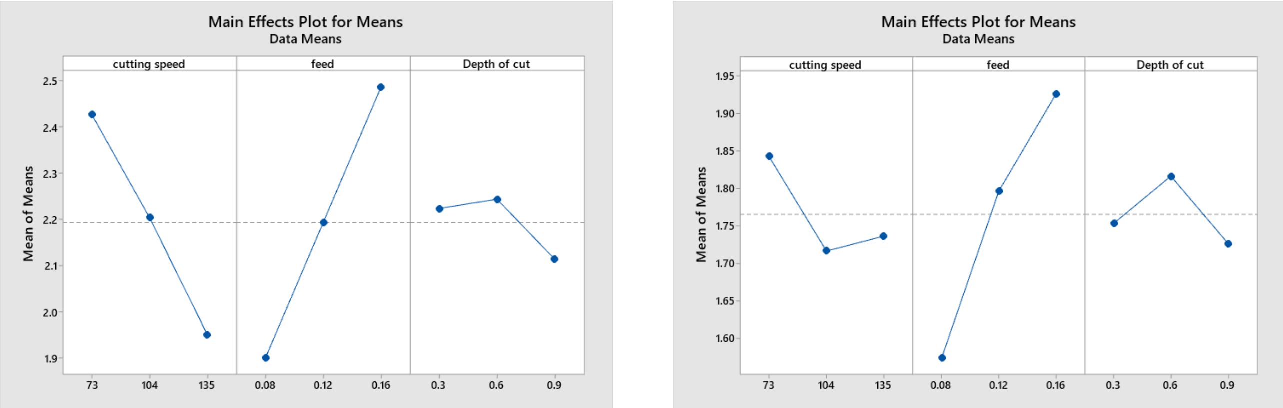


Fig. 7. surface roughness between no. of experiments.



(a) Manual supply (b) Device supply

Fig. 8. a, b. Main effect plots for process parameters and surface roughness of manual supply and device supply.

Table 4. Result of ANOVA for Manual Supply.

Source of variation	DOF	Sum of Squares	Mean Square	F Ratio	Contribution %
Cutting speed	2	6.08732	3.04366	12.189	37.42
Feed rate	2	8.84651	4.42325	17.714	54.38
Depth of cut	2	0.83230	0.41615	1.666	5.11
Error	2	0.49939	0.24969		3.070
Total	9-1=8	16.2655			100

Table 5. Result of ANOVA for Device Supply.

Source of variation	DOF	Sum of Squares	Mean Square	F Ratio	Contribution %
Cutting speed	2	0.692	0.346	2.50	11.27
Feed rate	2	4.834	2.417	17.51	78.75
Depth of cut	2	0.336	0.168	1.218	5.47
Error	2	0.275	0.137		4.49
Total	9-1=8	6.138			100

ANOVA analysis is employed to assess the importance of process parameters with percentage contributions. Table 3 displays the findings of the ANOVA research of machined surface roughness of a region. It has elapsed discovered that the feed rate is the most important contributing element in both the manually filled approach and the device-based supply method.

Surface roughness is typically impacted by the process factors that are taken into account. The major impact figure in Figure 8 is constructed utilizing process factors such as cutting speed, feed rate, and depth of cut. The feed rate has an impact on the surface roughness. Augmenting the feed rate leads to rise in surface roughness due to elevated friction between the tool and the contact area of the work piece.

5. CONCLUSION

The conclusions obtained from this investigation are:

- Electromagnetic stir casting employed for propagation of Al-SiC-MWCNT and it has better stirring action than mechanical type stir.
- Machined surface roughness is measured using manual and device-based supply of solid lubricants. Solid lubricants are smeared when tool and work piece contact which is used for formation of lubrication film around the cutting zone. This will be helpful for introducing lubricious nature and minimized frictional effect.
- The result of experimentation is indicated that manually filled solid lubricants are performed like uncoated inserts in case of starting of machined area and gets reduced due to solid lubrication effect. In case of device based solid lubrication supply, the roughness values are equal form start to end of the machined area.

- Result of device based supply is performed better when compared to manual filling supply. It is realized that uniform supply, appropriate solid lubricant on the micro hole and continuous supply. This work will be useful to understand the difficulty faced while application of solid lubricant.
- Statically analysis is carried out using ANOVA and the result indicated that feed rate is the most important aspect which influences the surface quality. The significant contributions are 65% from manual filling and 72% from supply using device.
- Better lubrication is achieved using solid lubricant (WS2) and it has significant advantages in terms of structure with less shear, brittle, easy to smear when tool and work piece contact, less shear strength, hexagonal layer and less frictional coefficient.
- EDD is used for introduce micro hole for retaining solid lubricant while manual and device supply. It has advantages in terms of minimum heat affected zone and good accuracy in dimension.

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