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INVESTIGATION ON AL-SIC-MWCNT METAL MATRIX COMPOSITE USING SOLID LUBRICANT, CERAMIC COATED AND CRYOGENIC CUTTING CONDITIONS IN TURNING PROCESS

Machining with clean and ecofriendly is current objective in manufacturing industries. Researchers are focusing on textured cutting tool inserts for a rake face coupled with solid lubrication to enhance a clean approach in machining. But there are a few issues with solid lubricants, such as supply methodology and durability at high temperatures. To avoid this issue, two different approaches are attempted. The first approach is textured cutting inserts are coated with titanium nitride (TiN) ceramic elements and the second one is cryogenic treatment. Micro hole pattern texturing on rake face is introduced. Textures are introduced using **Electrical Discharge Drilling (EDD)** to improve the dimensional accuracy of micro hole. Al based Metal Matrix Composites (MMC) with **Multiwalled Carbon Nano Tube (MWCNT)** is used as workpiece material. The machining performances are studied with the input process parameters of machining speed, feed rate and depth of cut. surface roughness and power consumption are considered as output parameters. The result is that machining performance is improved with cryogenically treated cutting inserts than ceramic coated and solid lubricant filled textured tool inserts as 7%-10% of surface roughness reduction and 9% to 20% power consumption reduction using textured inserts with cryogenically treated. The limitations of solid lubrication are eliminated by cryogenically treated cutting inserts and TiN ceramic coated tool. The cryogenically treated tool inserts exhibit enhanced hardness and strength. This research work promotes dry machining effectively with the help of cryogenically treated textured tool.

Keywords: Textured cutting inserts; Solid lubrication; Ceramic coating and cryogenically treated tool inserts

1. Introduction

In metal cutting process, heat is induced due to plastic deformation which can be eliminated using cutting fluid. Hydrocarbon oil-based cutting fluid are preferred by industries, but it creates environmental issues. In general, hydrocarbon oil-based cutting fluid generates environmental issues (contamination, pollution of ground water), operator health issue and disposal to the environment [1-3]. To avoid these issues, different approaches are attempted by researchers to find the optimum parameters for dry machining. Textured cutting inserts with cryogenically treated textured tool has the significant advantages of promoting dry machining by eliminating conventional cutting fluid as well as solid lubrication which leads to sustainability in machining. generally, in machining process, heat is developed because of plastic deformation which can be decrease using the application of cutting fluid. To avoid these issues, different approaches are attempted to convert green manufacturing namely dry machining, minimum quality lubrication [4], cryogenic machining [5] and vegetable oil-based coolant [6]. On the other hand, few drawbacks related to the above methods flow properties at cold condition, oxidation related issue at higher temperature of vegetable oil as cutting fluid [7], embrittlement properties due to cryogenic treatment [8,9], supply device in MQL [10], special equipment for cryogenic cooling [11]. In order to reduce environmental issues, researchers have identified texturing with solid lubrication as a desirable alternate cutting condition. The sustainability idea in machining is enhanced by introducing micro holes or grooves on the rake face of the cutting inserts and embedding them with solid lubricants [12]. Textured area with solid lubrication is observed to provide lubrication effect on tool-chip interface. Textured tool means it is having feature of micro pattern on cutting surface. this feature helps to reduce friction between tool and workface, acts as chip breaker, reduces tool chip contact and also reduces chip evacuation and recutting of chips and acts as a retainer for solid lubricant. The enhanced lubricant nature of solid lubricants are produces thin film of lubrication when the point of frictional heat [13]. Few issues are with solid lubrication such as supply

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to the machining zone, chemical reaction with parent materials, oxidation with more than 500°C and its durability [14]. Hence, researchers attempted another alternative approach i.e., ceramic coated textured inserts with dry conditions and cryogenically treated inserts with dry conditions. Tungsten carbide tool is the first preference by manufacturer due to low cost and easy availability. Various ceramic coated (Titanium Nitride, alumina and titanium carbide) tungsten carbide tools are available in market. Titanium Nitride (TiN) based ceramic coated cutting inserts are preferable due to its mechanical properties, low coefficient of friction between tool-chip interface, wear resistance and good machinability aspect [15]. Another cutting condition namely cryogenically treated cutting tool inserts are preferred to promote dry machining. Treatment in cryogenic condition is a type of heat treatment process which is used to enhance the properties of cutting tool. It is used to increase the density, secondary carbide formation and homogeneous distribution which leads to increase the hardness and wear resistance. chemical reaction of solid lubrication discussed in their work; molybdenum disulfide solid lubricant was attempted. The result revealed that MoS_2 reacted and formed FeS under steel surface [16]. AMATO et al. [17] investigated about solid lubricant coating and its performance improvement in high temperature applications. In their work, CaF_2 was selected as solid lubricant and its wear and frictional coefficient were determined. Surface film was most important in reduction of coefficient of friction. The result revealed that wear resistance temperature was better up to 100 to 600°C. Rivero et al. [18] investigated about the effect of coating on dry machining performance. They have pointed out MoS_2 had sensitive to higher temperature and started to oxidize as MoO_3 when the temperature in the range of 450°C. The result observed that MoS_2 was suitable for low range of cutting speed than high range of cutting speed. Tannous et al. [19] investigated the mechanism of solid lubricant and its lubrication layer mechanism. The result revealed that the formation of lubrication film. Also, it was observed that a chemical reaction MoS_2 on the work surface through native iron oxide layer or via the metal atoms. Zhang et al. [20] used soft and hard coating on textured cutting inserts in turning process. PVD process was used to carry out soft coating (WS2) and hard coating (TiAlN). Textures were introduced on rake face by LASER source. It has been observed that significant improvement in machining performance with hard coating. Mishra et al. [21] conducted machining performance of AlTiN and AlCrN coated laser textured cutting inserts. Initially, studied the coating morphology and its elemental analysis and finally, machining performance on titanium alloy with dry conditions using coated inserts was performed. The result showed that enhanced performance with coated textured inserts.

Arul Kirubakaran et al. [22] conducted machinability study using ceramic coated textured cutting inserts on titanium alloy. In their study, two different ceramic elements such as TiN and TiAlN ceramic element. Machinability aspect such as surface roughness and tool wear were investigated. The result revealed that machining performance was improved with TiN coated element. Khan and Maity [23] conducted a comparative study of treated and untreated inserts. Microhardness of treated inserts was shown improved than untreated. Wear resistance was shown better when compared to untreated inserts. Shear crack and lateral flow were the important for chip analysis. Mechanical properties were improved for cryogenically treated carbide inserts. The result revealed that treated inserts were performed better than untreated inserts. Karthikeyan and Balamurugan [24] conducted machinability cryogenic treatment on cutting tool inserts and performed machinability study. Multi objective optimization was conducted using Taguchi coupled grey concept as well as ANOVA. The result pointed out cryogenic treatment machining leads to dry machining. It leads to environmental free machining. Results are optimized effectively using grey concept. Palanisamy et al. [25] conducted performance study using cryogenically treated textured cutting inserts in turning process. Performance study was conducted with treated and untreated inserts. The result pointed out treated tool was effectively resisted chipping of tools during machining. Treated tool was changed the property inters of microstructure which was used to enhance the tool life. Devaraj et al. [26] 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 literature, it is understood that alternative cutting condition to eliminate hydrocarbon oil-based cutting fluid. Texture with solid lubrication is easiest alternative cutting condition. Micro groove is introduced on rake face to fill the solid lubricant for obtaining thin lubrication film [34]. But it is observed that few issues in terms of supply, oxidation and parent material corrosion. Hence, two different other approaches are noticed to avoid such issue. It is noticed that ceramic coated and cryogenically treatment on cutting tool is used to improve machining performance. Also, it is observed that micro texture using LASER and EDD are shown advantages and disadvantages in few aspects. Hence, in this research an approach towards the combined advantages of cutting inserts with texturing as well as ceramic coating and cryogenically treatment. The results of surface roughness with ceramic coated and cryogenically treated cutting inserts performance is compared with solid lubrication- and ceramic coated while turning of Al-MMC.

2. Methodology

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 (Aluminum based Metal Matrix Composites). It has few advantages in terms of stirring action. In electromagnetic stir casting process, Fig. 1 Electromagnetic stir casting setup.

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

Fig. 1. Electromagnetic stir casting setup

(force per unit volume) influences the electromagnetic force and better stirring action is achieved and will be useful to obtain defect free composite. SEM images can be used to analyse tool wear, surface roughness, and microstructural changes in the machined material. Fig. 2. SEM Image of Al-SiC-MWCNT. MWCNTs (Multiwalled Carbon Nano Tubes) with SiC had a synergic effect, resulting in improved strength and dispersion. The purpose of this research was to create metal matrix composites (MMCs) using AA6061 alloy and multi-wall carbon nanotubes (CNTs) as reinforcing materials. The scanning electron microscopy (SEM) pictures and optical micrograph images offer rich information on the microstructure of the created MMCs of various compositions. The SEM images show a homogenous distribution of reinforcement and a strong connection between the MWCNT and AA6061 matrix in the composites, demonstrating the Electro Magnetic stir casting approach's efficiency for producing AA6061-MWCNT metal matrix composites. In comparison to the original metal, the microhardness and impact strength have increased and preferred in most of the applications such as automobile, marine and aerospace applications.

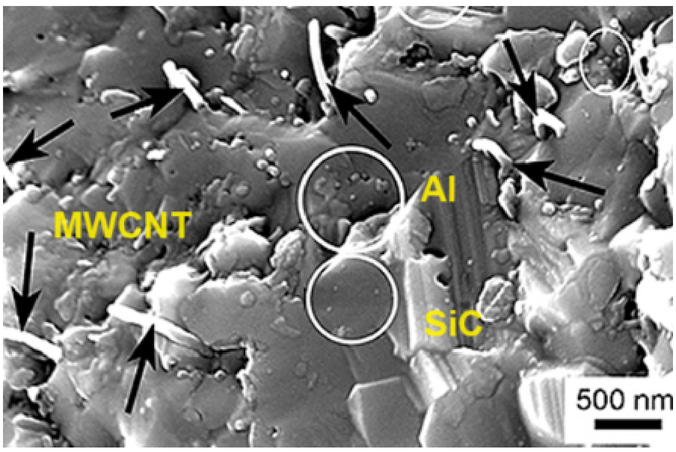


Fig. 2. SEM Image of Al-SiC-MWCNT

TABLE 1 shows composition of Al-SiC-MWCNT key elements of the workpiece identified by EDX. 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. Fig.3 shows EDX image of Al-SiC-MWCNT.

Energy Dispersive X-ray Spectroscopy (EDX) is an analytical technique used in conjunction with SEM to determine the elemental composition of a sample. EDX identifies and quantifies the elements present in the sample by analyzing the characteristic X-rays emitted when the sample is bombarded with the electron beam.

TABLE 1

Al-SiC-MWCNT material composition

Element Line	**Weight %**	**Weight % Error**	**Atom %**	**Atom % Error**
C K	1.09	±0.31	2.42	±0.69
Al K	86.44	±1.01	86.75	±1.00
Si K	11.37	±0.76	10.82	±0.72
Mg	1.01	—	—	—
Total	100.00		100.00	

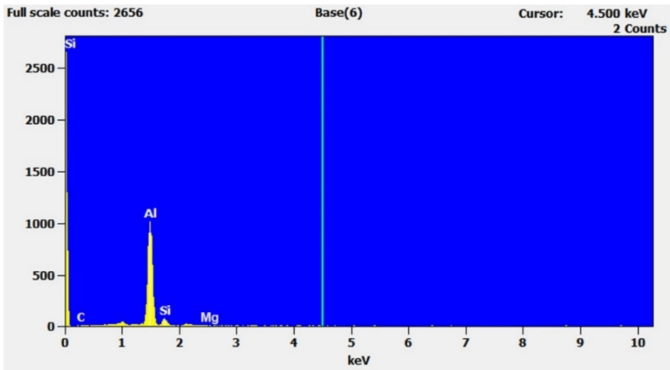


Fig. 3. EDX image of Al-SiC-MWCNT

Plain geometry with uncoated carbide inserts is selected as cutting tool inserts (make WEDIA-CNMA 120408). Plain geometry with uncoated carbide inserts is selected as cutting tool inserts (make WEDIA-CNMA 120408). liquid-based lubricants hazardous to environment and soil contamination, so in this study considering alternate methods for Achieving ecofriendly Dry machining. Those are Texture with solid lubricant, ceramic coated tool and cryogenically treated tool insert. These can be acted as an alternative one to hydrocarbon oil-based cutting fluids due to its machining performance.

Electrical discharge drilling method is used for producing texture on cutting tool inserts. Generally, researchers are used LASER source for introducing texture on rake face. But few issues are noticed with LASER source are dimensional accuracy and heat affected zone. Fig. 4 shows EDD the LASER source used for texture produced on cutting inserts. Fig. 5 shows the SEM image of hole produced by EDD hole and LASER source. Fig. 6 shows cutting inserts with micro-hole. Design parameters of micro hole textured cutting inserts considered are diameter of the hole, depth of the hole and pitch between the holes. TABLE 2 presents the considered design parameters levels. The value of design parameters is considered basis of previous literature and trial experiments [32-33].

Fig. 4. Electric Discharge Drilling (EDD) and LASER source

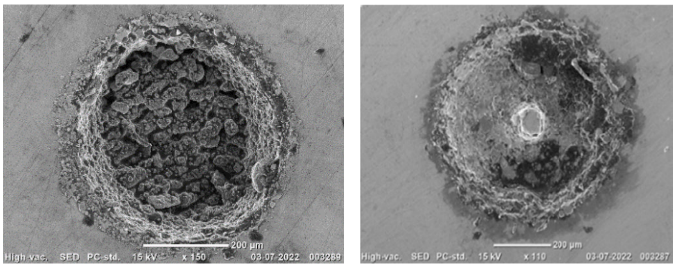
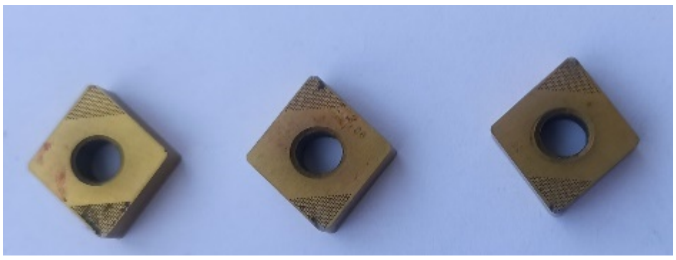


Fig. 5. SEM image of EDD and LASER micro hole texture

Texture with uncoated inserts



TiN coated texture inserts

Fig. 6. Cutting inserts with micro-hole

Experiments are performed with the help of Taguchi L_9 orthogonal array. Turning process is carried out using CNC turning machine (make of Pride-Jaguar). TABLE 3 shows the process parameters used to perform experiments.

TABLE 2

Micro hole textured inserts design parameters

Design parameters of micro hole	**Diameter of micro hole**	**Depth of micro hole**	**Distance between micro hole**
	300 μm	400 μm	200 μm

TABLE 3

Process parameters and their levels

Parameters /Levels	**Level 1**	**Level 2**	**Level 3**
Cutting speed in m/min	73	104	135
Feed rate in m/rev	0.08	0.12	0.16
Depth of cut	0.3	0.6	0.9

Texture on cutting tool inserts is used for filling solid lubricant and providing appropriate cooling and lubrication. The important task in the solid lubrication is supply appropriate quantity to the cutting zone. Many of the literature are not mentioned about its supply methodology. It is understood that it is directly filled in the groove manually. In this investigation, a supply device is used to achieve solid lubrication. Fig. 7 shows the CNC setup with solid lubrication supply system. Tungsten Disulphide (WS_2) is selected as solid lubricant for this research which has significant properties of structure with hexagon layer, texture II and good lubricious nature. As mentioned earlier, the problems associated with solid lubrication are supply to the cutting zone; there is a chance of a chemical reaction in between parent materials and solid lubricant, temperature withstanding properties and its durability. Hence, textured insert is coated with TiN ceramic element for promotion of dry machining as well as sustainability of machining. TiN has excellent lubricant and also leads to lower co-efficient of friction. Sputtering process is used for TiN coating on cutting tool inserts and thickness is maintained as 3 to 4 μm. Fig. 8 shows SEM image of coated inserts.

Fig. 7. CNC setup with solid lubrication supply system

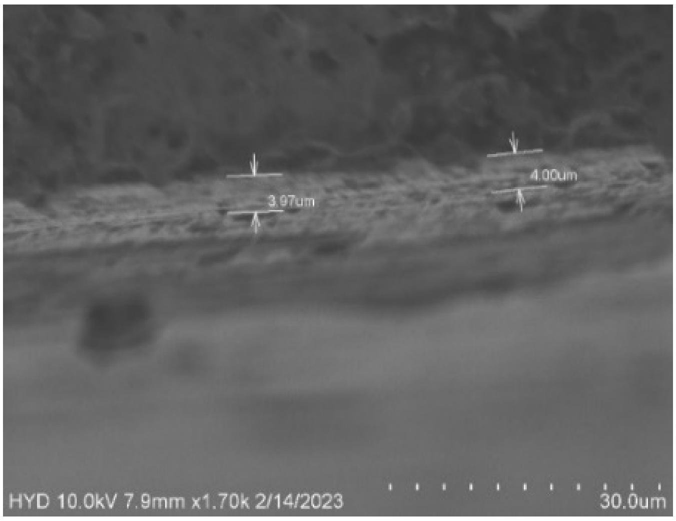


Fig. 8. SEM image of coated inserts

In this work, as mentioned earlier another approach of cryogenically treated cutting inserts after texturing is used. The following procedure are followed for cryogenic treatment for textured cutting inserts. Fig. 9 shows the cryogenic setup for treatment of cutting inserts and its treatment cycle. In this initial stage, surrounding temperature is reduced into −196°C at a constant rate of 2°C per minute. Soaking time is considered as 24 Hrs and −196°C. In this stage, temperature is slowly increased from −196°C to atmosphere temperature by 2°C per minute. Once the surrounding temperature is obtained, need to increase the temperature to 200°C at a constant rate of 2 C per min, and maintain it for 2 h. Finally, the temperature in to surrounding temperature at a controlled rate of 2°C per minute

Fig. 10 indicate the samples after machining process. Surface roughness of the machined area is obtained by SJ 210 roughness tester. Average value Ra can be defined as deviation of roughness profile with integral value. Generally, it can be obtained from three different place of machined area and its average. Power consumption during machining can be estimated by mathematical expression. Power consumption is the multiplication of main cutting force and its cutting velocity. Selection of cutting force device and its accuracy plays a vital role in measurement of actual cutting force involved during machining. Hence, direct measurement of power consumption is always preferable to avoid any measurement error and enhance accuracy. A power quality analyzer is used to measure the power consumed while machining. This can be directly connected with power panel board and display results while machining. Fig. 11 shows surface roughness tester and power quality analyzer. TABLE 4 represents the experimental results.

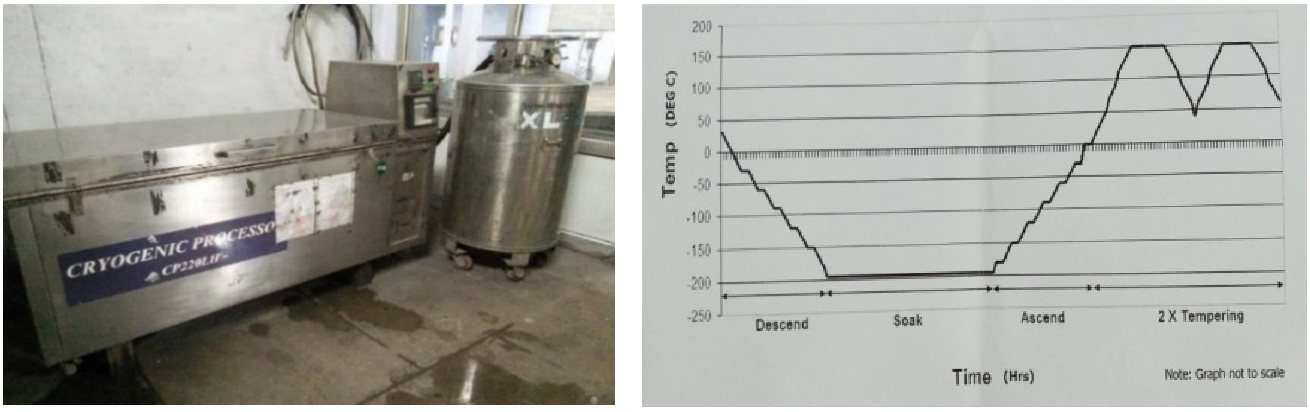


Fig. 9. Cryogenic setup for treatment of cutting inserts

TABLE 4

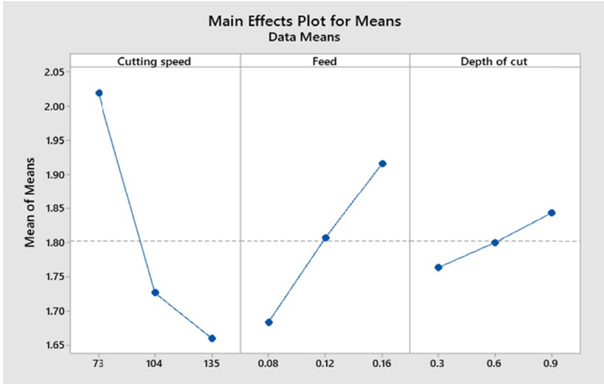
Experiment results

Sl. No.	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Texturing with solid lubrication		Texturing with ceramic (TiN) coated		Texturing with cryogenically treated	
				Surface roughness in µm	Power in kW	Surface roughness in µm	Power in kW	Surface roughness in µm	Power in kW
1	73	0.08	0.3	1.82	0.182	1.75	0.176	1.67	0.16
2	73	0.12	0.6	2.03	0.196	1.95	0.186	1.78	0.154
3	73	0.16	0.9	2.21	0.242	2.17	0.227	1.98	0.208
4	104	0.08	0.6	1.64	0.143	1.61	0.138	1.45	0.114
5	104	0.12	0.9	1.73	0.153	1.62	0.147	1.58	0.132
6	104	0.16	0.3	1.81	0.168	1.74	0.156	1.51	0.131
7	135	0.08	0.9	1.59	0.131	1.53	0.126	1.32	0.105
8	135	0.12	0.3	1.66	0.141	1.59	0.131	1.41	0.116
9	135	0.16	0.6	1.73	0.156	1.67	0.142	1.44	0.111

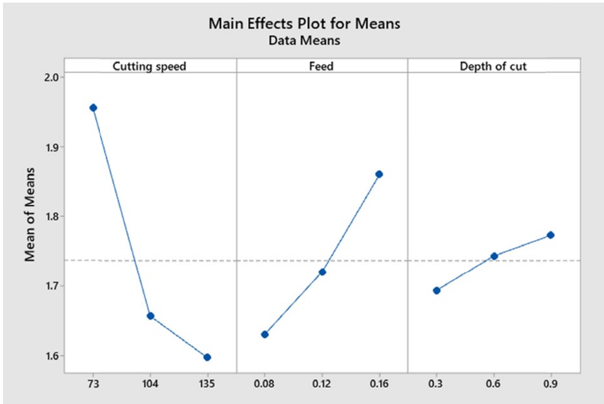
Fig. 10. Indicate the samples after machining process

Fig. 11. Shows surface roughness tester and power quality analyzer

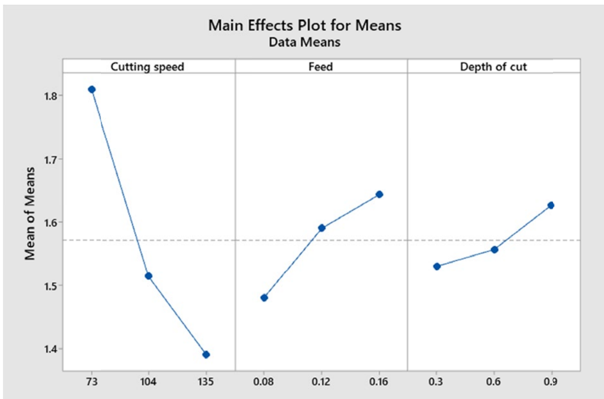
TABLE 3 shows the experimental results obtained using L_9 orthogonal matrix The value of design parameters is considered basis of previous literature and trial experiments. Surface roughness is an indication of machinability and enhances functional life of the machined component. In manufacturing sector, energy utilization plays a significant role in economic aspect, and global warming. Main effects on each output parameters are plotted and analysed the results. Textured cutting inserts with solid lubrication is achieved using a specially designed and fabricated device. TiN coated textured cutting inserts with dry machining and cryogenic treatment on textured inserts are performed to overcome the difficulties of solid lubrication [20]. The results are compared with textured inserts with solid lubrication, textured inserts with TiN coated textured inserts and textured inserts with cryogenically treated inserts Figs. 12a-c and 13a-c show main effect of plot and its responses.



a. Surface Roughness main effect of plot and its responses for solid lubrication



b. Surface Roughness main effect of plot and its responses for Ceramic Coated

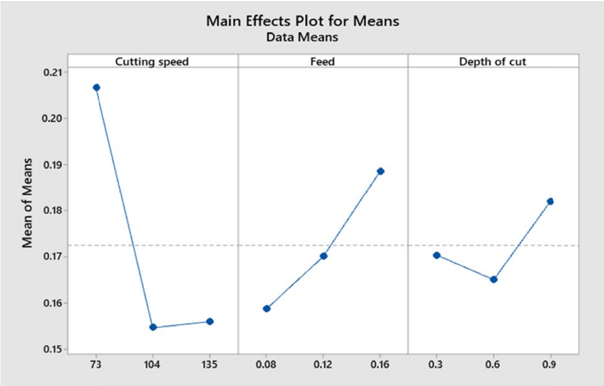


c. Surface Roughness main effect of plot and its responses for Cryogenically treated tool insert

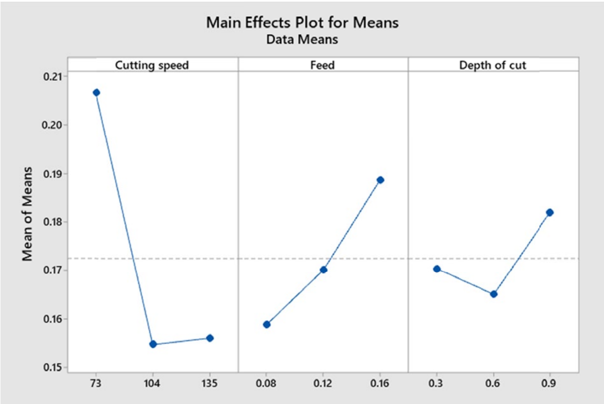
Fig. 12. Main effect plots and its responses

3. Results and discussion

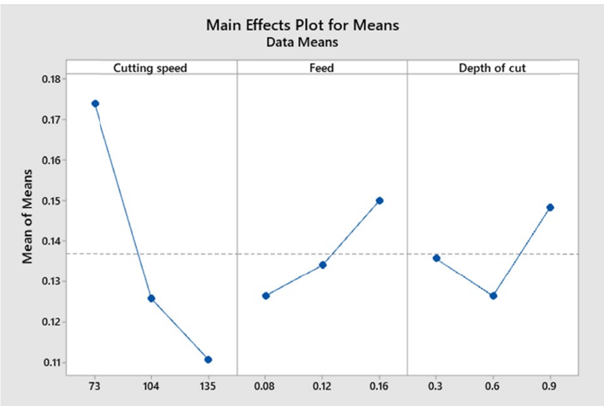
In this study, surface roughness and power consumption are considered as output parameters. Surface texturing on cutting tool inserts is available with different pattern. Machining performance is significantly influenced by types of texture pattern. The different patterns are micro hole, parallel, elliptical, perpendicular and cross type. During metal cutting chip flow is difficult to



a. Power consumption main effect of plot and its responses for solid lubrication



b Power consumption main effect of plot and its responses for Ceramic Coated



c. Power consumption main effect of plot and its responses for Cryogenically treated tool insert

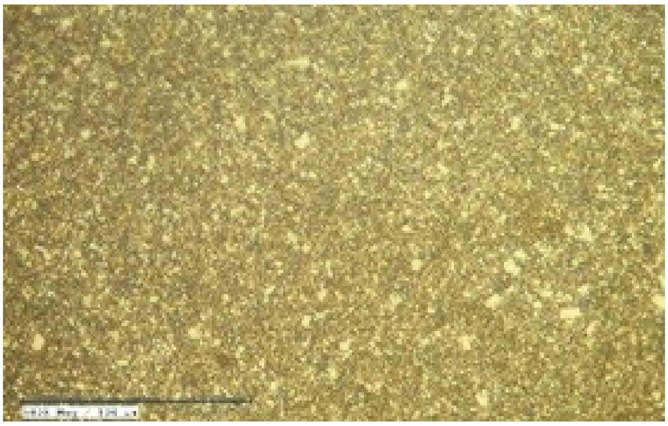
Fig. 13. Main effect plots and its responses

assume, hence micro hole type textures are advantages in terms of not direction dependent than other type of textured pattern. [28] explained the advantages of aerodynamic lubrication effect in between the tool-chip interface and leads to anti-adhesion effects. Hence, good machining performance is observed due to minimum tool-chip contact length and less friction.

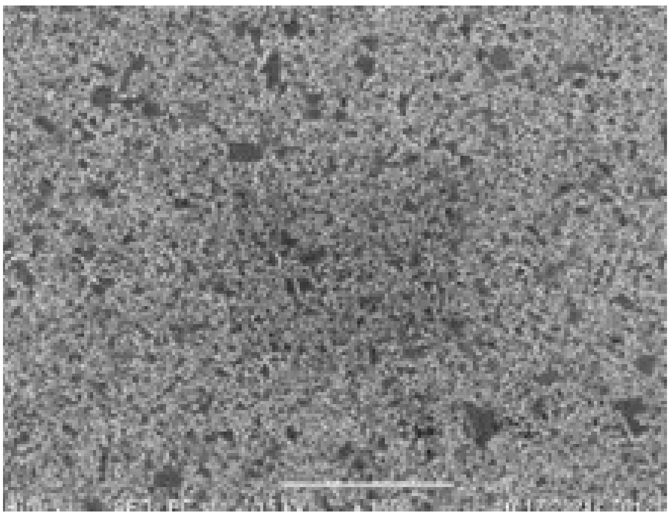
Surface texturing on cutting tool inserts is available with different pattern. Machining performance is significantly influenced by types of texture pattern. The different patterns are micro hole, parallel, elliptical, perpendicular and cross type. During metal cutting chip flow is difficult to assume, hence micro hole type textures are advantages in terms of not direction dependent than other type of textured pattern. It has other advantages of aerodynamic lubrication effect in between the tool-chip interface and leads to anti-adhesion effects [27]. Hence, good machining performance is observed due to minimum tool-chip contact length and less friction Solid lubrication is acted as alternative cutting conditions. Generally, it is a dry powder form which generates thin lubrication film when frictional heat at the point of heat. This is called as thermal expansion of solid lubricant [28]. In this work, tungsten disulfide is used as solid lubricant. It has lower shear strength, hexagonal layered structure, low co-efficient of friction, thin and brittle in nature due to these properties easily smeared and forming a thin layer during the process [29]. Hence, better surface quality is observed with better lubricity and anti-adhesion effect. Few issues with solid lubrication are also noticed appropriate quantity, oxidation at higher operating temperature and chemical rection with parent materials. The various WS2 solid lubricant properties are physical properties (adhesion restriction), chemical properties (oxidation resistance), mechanical properties (lower shear strength) and micro structural (lamellar structure II). From the better properties WS2 solid lubricant, low value of coefficient of friction and better lubricity are observed. The combined advantages of texturing and solid lubrication, better machining performance is noticed.

The difficult task in solid lubrication supply of appropriate quantity to the cutting zone needs a device or special method. Researchers in the field of solid lubricant have not mentioned about its supply methodology. Few other issues like chemical reaction in parent material and chemically instable [30]. At higher temperature. Also, more than 700°C, it is getting oxidized and leads to wear. The possibility of withstanding the solid lubricant at high temperature is difficult. To overcome the above issues of solid lubrication, two different approaches is attempted in this work such as ceramic coated and cryogenic treatment on textured cutting inserts. TiN ceramic coated textured inserts with dry condition is attempted. TiN ceramic coated on cutting inserts is applied by PVD method. The lubricious nature of TiN coating is used to reduce temperature during machining in tool-chip interface. It is noticed that, TiN coated cutting inserts are provided good surface finish than solid lubrication due to its minimum coefficient of friction and good wear resistance properties. Micro hole textured insert acts as chip breaker and create high localized pressure during chip flow. This can lead to reduce the cutting force during machining process. Power consumption is the product of main cutting force and its cutting velocity. Hence, reduced power consumption values are noticed with micro hole textured inserts. The result of TiN coating on cutting tool insert is provided appropriate

lubrication by minimizing the co-efficient of friction. It can be achieved due to hardness of the TiN coated layer which is higher than work piece surface. TiN coated tool such as good abrasion resistance, hardness, thermal stability and uniform rate of wear progress. From the experimental results, it is understood that textured inserts with TiN coating enhances dry machining effectively. Cryogenic treatment is a type of heat treatment process which is executed at less than atmospheric temperature. In this, specimens (cutting tool inserts) are cooled with the help of control unit and liquid nitrogen gas in the range of –80 and –196°C. The outcome of the process is used to enhance property of cutting tool inserts. This is due to transformation of austenite to martensite during cryogenic treatment process. It will be used to increase the hardness and fine microstructure of the tool inserts. Wear resistance of the cutting tool inserts are enhanced through carbide distribution in the microstructure [31]. Cryogenic treatment is used to increase the density, secondary carbide formation and homogeneous distribution which leads to increase the hardness and wear resistance. Fig. 14a-b show microstructure and SEM image of cryogenically treated forming tool. The result of SEM image and microstructure indicated that eta carbide formation after cryogenic treatment. Cryogenic treatment is also used to enhance the thermal conductivity of the forming tool. This will be used to heat distribution capacity and dissipation during forming effectively.



Microstructure



SEM image

Fig. 14. Microstructure and SEM image of cryogenically treated tool

4. Conclusions

1. Micro hole textured cutting inserts are not direction dependent characteristics. EDD holes are having the advantages in terms of accuracy of holes and heat affected zones than holes produced by LASER This can be used to dimensional accuracy and followed by functional characteristicsin terms of storage capacity and area of cutting inserts.
2. Cutting tool inserts with texturing on rake face is one of the easiest another cutting conditions but it has drawback in terms of supply, chemical reaction with parent materials and durability. TiN ceramic coated insert and cryogenically treated inserts are used to overcome this issue. Cryogenically treated inserts are performed better when compared with TiN ceramic coated insert and solid lubrication.
3. It is noticed that reduced surface roughness and power consumption by using TiNas well as cryogenically treated and coated inserts. Thus, 12% to 20% of surface roughness reduction and power consumption reduction using textured inserts with TiN coated than solid lubrication. Similarly, 7%-10% of surface roughness reduction and 9% to 20% power consumption reduction using textured inserts with cryogenically treated.
4. Marginal difference between the performance of cryogenically treated and TiN ceramic coated inserts. Both methods are used to promote dry machining effectively and eliminating difficulties related to the solid lubrication. Also, it is observed that there is afuturedirectionstudy of optimization in between cryogenically treated and TiN ceramic coated inserts toenhance dry machining.
5. Solid lubricants are possessed better lubrication properties due to its low value of shear strength, adhesive properties and less coefficient of friction. It has significant property of easily smeared, thermal expansion and forms a thin layer. The primary issue with solid lubrication is supply to the cutting zone. TiN ceramic coating has advantages of lubricious in nature, hardness, thermal stability and minimum coefficient of friction. Cryogenic treatment on cutting tool insert give increased hardness, wear resistance, secondary carbide formation and homogeneous distribution.

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