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Experimental Examination of Tool Wear During Turning of Ti-Grade 2 Alloy in Dry and Minimum Quantity Lubrication (MQL)

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Abstract- *In any manufacturing industry cost and productivity are the major concerns to be taken care. There are several factors which can be used to control these factors and while it comes to machining tool wear plays a major role in deciding the productivity and cost of the machining process. Recently many studies have been done on the different alloys of titanium and it is found to be very useful and difficult to machine material as well. In this work turning of one of the titanium alloys is used to study the tool wear behavior during dry and minimum quantity lubrication (MQL) machining conditions. In the current work tungsten carbide (WC) insert is used for machining process. After the machining Taguchi's analysis is used to analyze the results obtained after the machining. In this work spindle speed, feed, and depth of cut are taken as the input parameters along with the machining condition. From the results it is found that MQL provides the better results to minimize the tool wear.*

Keywords: *Tool wear, Turning, Dry machining, Minimum Quantity Lubrication (MQL).*

I. INTRODUCTION

Titanium is considered as difficult to machine material due to its low modulus of elasticity, poor conductivity, and high chemical reactivity [1]. Out of which low elasticity leads to poor surface finish and due to other two causes several wear mechanism and reduces the tool life, which results in higher cost of machining of titanium alloys. In order to reduce the cost and difficulty of machining of titanium alloys several solutions were found such as heating of workpiece, use of different cooling and lubrication techniques and improvement in tool material etc. [2-4]. Out of the above mentioned techniques several cooling and lubrication techniques are being primarily used for improving the machinability of titanium alloys. To improve the machinability of these alloys Cryogenic cooling, high-pressure coolant (HPC) and Minimum quantity lubrication (MQL) were used in various researches [5-8]. It is found from many studies that all the above mentioned techniques reduce the machining issues of titanium. The current work is focused on the machining of titanium grade with MQL.

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MQL is the technique of cooling and lubrication in which very small quantity of cutting fluid is used for the purpose of cooling ad lubrication along with compressed air so that the cutting fluid reaches cutting zone properly and causes cooling and lubricating effect [9]. Initially MQL was used for lubrication purpose in bearings but by the time it has found its application in the field of machining too [10-12]. In MQL the cutting fluid have make aerosol with pressurized air, hence the cutting fluid used in MQL should possess an additional property to form aerosol easily with air along with general properties required for good lubricant i.e. higher flash point, boiling point, molecular-weight, oiliness, strength and the cutting fluid used should be bio-degradable, non-toxic. Most common cutting fluids used in MQL are vegetable oils and synthetic ester. With the time many improvements have been done in the use of MQL too, for better results MQL has been used with many advancements like use of nano-particles (MQL+NP), ionic fluids(MQL+IL), MQL with RHVT (Ranque-Hilsch Vortex Tube), cryogenic cooling (CMQL) and super cooled CO_2 (MQL+SC CO_2). From the previous works and literature it is found that out of these advancements use of nano-fluids found to be most promising in the field of MQL, this is described below in the table 1. This table shows that employing MQL with nano-particles has positive impact on all the response parameters listed in the table *viz.* surface quality, tool life, and cutting forces. In case of MQL with ionic liquids there are improvements in results of surface quality and cutting forces while in case of tool life there was no improvement. MQL with RHVT showed the improvement in surface quality and tool life but no improvement for cutting forces. Cryogenic MQL results are similar to the MQL with ionic liquids i.e. there are improvements in context of surface quality and cutting forces while it has no improvement in case of tool life. With super cooled CO_2 showed the improvement in surface quality and tool life without reducing the cutting forces. Hence, from the given table it can be concluded that MQL with nano-particles is the most suitable for machining operations.

Table-I: Comparisons of Different Advancements in MQL [11]

Types of MQL/ Improvement	MQL + NP	MQL+IL	MQL+ RHVT	CMQL	MQL+SC CO_2
Surface Quality	✓	✓	✓	✓	✓
Tool Life	✓	×	✓	×	✓
Cutting Forces	✓	✓	×	✓	×

It can be clearly observed from the table that MQL with nano-particle influences the almost each and every response parameters. MQL can be employed for a machining process externally by using external nozzles or internally through the spindle. As discussed earlier tool wear is major concern during the machining operation to reduce the tool wear various alternatives are studied and it was found that MQL is one of the solutions for the machining processes. Sreejith in 2008 observed lesser too wear and built-up-edge formation during the drilling of Al 6061 [13]. Sohrabpoor et al. observed reduction in tool wear during turning of AISI 4340 stainless steel in MQL using soluble oil as cutting fluid in comparison to dry, air cooled and wet machining conditions [14]. These results were also supported by the experiments done by Dhar et.al. turning of AISI 1040 steel [15]. Thamizhmanii and Rosli observed 43.75% increase in tool life with MQL compared to dry machining while milling of Inconel 718 [16]. Attanasio et.al. noticed significant increase in tool life during turning of 100Cr6 normalized steel with MQL in comparison to dry machining[17]. All the above works elaborate the success of MQL over other mode of cooling and lubrication, in addition to that current work is also presenting the comparison of tool wear during turning of titanium grade 2 alloys under dry and MQL using nano-fluid.

II. METHODS AND MATERIALS

In the present work turning of commercially pure titanium (Ti- Grade 2) is done by using TNMG 160404- THM tungsten carbide insert on OKUMA's semi-automatic high speed lathe to achieve the objective of the study under nano-fluid based MQL and dry machining condition. The material used for the experimentation i.e. Ti-Grade 2 falls under difficult to machine material , which is discussed in the earlier section of this work. So, it requires the use of convenient cutting fluid for the machining purpose. On the basis of literature review vegetable oil is selected for the experimentation which is suitable for both the machining of titanium and MQL conditions. X-Gnp-H-25 graphene nano-plates are used as the nano-particle to prepare the nano-fluid in which canola oil is used as the base fluid. For preparation of nano-fluid 300 mg of nano-particle is dispersed into the 300 ml of canola oil. To obtain uniform mixture sonication of the mixture was done which was followed by the stirring for 3-4 times.Process variables selected for the experiments are cutting condition i.e. dry and MQL, depth of cut, feed rate, and spindle speed. Whereas tool wear is taken as the response variable. For MQL cutting condition NOGA made MINICOOL MC3000 atomizer unit is used which works on the principle of venturi. In the atomizer unit aerosol is produced and this unit also consist of two nozzles to spray the lubricant at cutting zone. To measure the tool wear on the flank face of the cutting insert JEOL made SEM (scanning electron microscope) is used. During measurement of tool wear length of worn tool is measured at the flank face after the machining. During the tool wear measurement image of flank face of tool is taken and then the length of the worn tool is measured by using scales available in the SEM is measured and the image is also captured for the measurements. To analyses the effect of process parameter on the response variable a set of experiments is to done at various combinations of the input parameters. To obtain the various combinations for the experiments Taguchi design is used. This design method uses orthogonal array to give the minimum combinations of input parameters to perfume experiments. The set of experiments designed for experiments consist of four input parameters in which the cutting condition is taken as the categorical factor have two levels while other parameters i.e. depth of cut, feed rate, and spindle speed has three levels each show in Table 2. To design the experiments L18 mixed orthogonal array is used, this process was done on MINITAB 17. After the designing the experiments two cylindrical rods of Ti-Grade 2 having 500 mm length and 30 mm diameter for machining under each conditions. Table 3 shows the combinations of parameters designed to perform experiments.

Table-II: Process Parameters and Their Levels

Factor	Level 1	Level 2	Level 3
Cutting Condition	Dry	MQL	-
Depth of cut	.1	.3	.5
Feed-rate	.05	.1	.15
Spindle Speed	525	730	970

Table- III: Design of Experiments

Sr. No.	Type	Depth of cut (mm)	Feed rate (mm/rev)	Spindle speed (RPM)
1	1	0.1	0.05	525
2	1	0.1	0.1	730
3	1	0.1	0.15	970
4	1	0.3	0.05	525
5	1	0.3	0.1	730
6	1	0.3	0.15	970
7	1	0.5	0.05	730
8	1	0.5	0.1	970
9	1	0.5	0.15	525
10	2	0.1	0.05	970
11	2	0.1	0.1	525
12	2	0.1	0.15	730
13	2	0.3	0.05	730
14	2	0.3	0.1	970
15	2	0.3	0.15	525
16	2	0.5	0.05	970
17	2	0.5	0.1	525
18	2	0.5	0.15	730

III. RESULT AND DISCUSSION

In the present work tool wear is measured in terms of worn length on the flank face during machining. Figure 1 and 2 shows the tool wear measurement for a random run formed during the experiments, which is measured on the scanning electron microscope (SEM). It can be seen from the figures that in case of dry machining there is formation of built-up-edge is occurring too. To study the results obtained after the machining experiments signal-to-noise ratio is used. Table 4 shows the measurements of tool wear and S/N ratio obtained from Taguchi analysis.

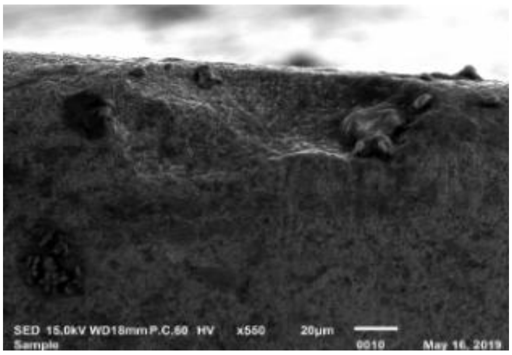

Fig. 1. Tool Wear in MQL Machining

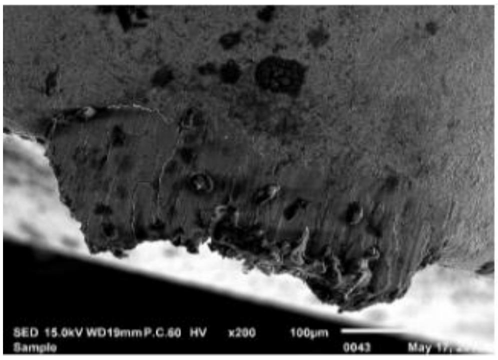

Fig. 2. Tool Wear in Dry Machining

Table IV: Measured Tool Wear for Several Runs

Run	CC	d	f	N	w	S/N ratio
1	1	0.1	0.05	525	55.67	-34.91
2	1	0.1	0.1	730	43.45	-32.76
3	1	0.1	0.15	970	30.29	-29.62
4	1	0.3	0.05	525	57.23	-35.15
5	1	0.3	0.1	730	49.19	-33.83
6	1	0.3	0.15	970	34.36	-30.72
7	1	0.5	0.05	730	51.45	-34.22
8	1	0.5	0.1	970	38.05	-31.60
9	1	0.5	0.15	525	61.05	-35.71
10	2	0.1	0.05	970	61.95	-35.84
11	2	0.1	0.1	525	81.58	-38.23
12	2	0.1	0.15	730	65.58	-36.33
13	2	0.3	0.05	730	72.95	-37.26
14	2	0.3	0.1	970	60.56	-35.64
15	2	0.3	0.15	525	84.95	-38.58
16	2	0.5	0.05	970	63.56	-36.06
17	2	0.5	0.1	525	85.31	-38.62
18	2	0.5	0.15	730	73.48	-37.32

CC= Cutting condition, d=depth of cut (mm), f=feed rate (mm/revolution), N=spindle speed (rpm), w=tool wear (μm)

Figure 3 shows the comparison of the tool wear obtained at several runs both the cutting conditions i.e. dry and MQL. It can be clearly observed from the plot that the results obtained in MQL condition are far better than the in dry cutting condition.

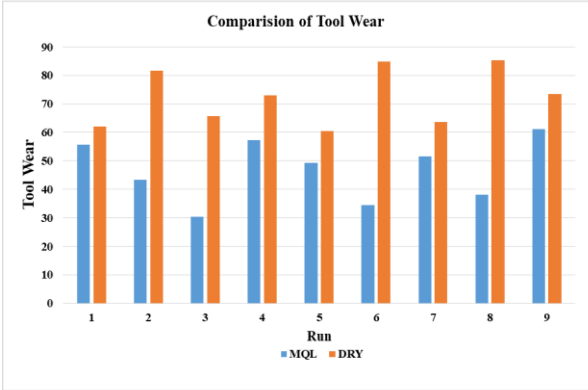

Fig. 3. Tool Wear Comparison Plot

To obtain the optimal parameters for the minimum tool wear the results of S/N ration and mean is analyzed with the help of main effect plots for mean and S/N ratio shown in Figure 4 and 5 respectively. From these figure it can be seen that the lower value of the tool wear is obtained in MQL cutting condition at lower depth of cut i.e. 0.1 mm, higher feed rate, and spindle speed i.e. 0.15 mm/rev and 970 rpm respectively. During MQL presence of lubricant would be the reason of lesser tool wear while smaller depth of cut reduces the load on the cutting insert and during higher feed and spindle speed engagement time of workpiece and insert is very less which results in lesser frictional and other forces hence results in lesser tool wear.

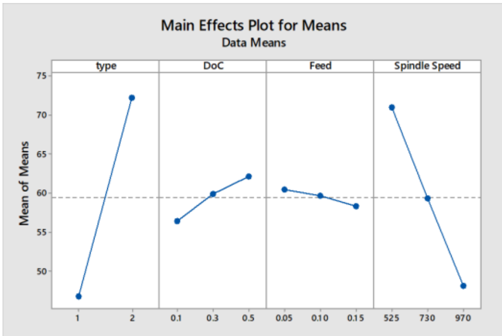

Fig. 4. Main Effects Plot for Means of Tool Wear

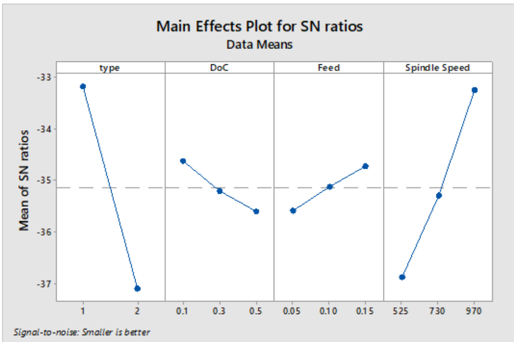

Fig.5. Main Effects Plot for S/N Ratios of Tool Wear

The above data is depicted in the form of table in the Tables 5 and 6 named response table for mean and S/N ratio respectively. In these tables mean and S/N of tool wear is shown for various parameters. These tables shows the order in which tool wear is affected by the various parameters, delta in the tables is the difference between the maximum and minimum values of mean and S/N ratios for different parameters and rank which decides the order in which the tool wear is influenced by input parameters. Higher value of delta shows higher influence of parameter. Hence, from the tables it is observed that cutting condition influences the tool wear the most followed by spindle speed and depth of cut respectively, while feed rate is the parameter which affect the tool wear the least.

Table VI: Response Table for Mean of Tool Wear

Level	Type (Cutting Condition)	DoC (mm)	Feed rate (mm/rev)	Spindle Speed (rpm)
1	46.76	56.43	60.48	70.97
2	72.22	59.88	59.69	59.36
3	-	62.15	58.29	48.13
Delta	25.46	5.73	2.19	22.84
Rank	1	3	4	2

Table VII: Response Table for S/N Ratios of Tool Wear

Level	Type (Cutting Condition)	DoC (mm)	Feed rate (mm/rev)	Spindle Speed (rpm)
1	-33.17	-34.62	-35.58	-36.87
2	-37.10	-35.20	-35.12	-35.29
3	-	-35.59	-34.72	-33.25
Delta	3.93	0.97	0.86	3.62
Rank	1	3	4	2

IV. CONCLUSIONS

Following conclusions are drawn from the obtained experimental data.

1) It is found from the experimental data that the cutting condition highly influences the tool wear and from the previous section it can be concluded that MQL is far better option for the machining of Ti-Grade 2 in comparison to dry machining.
2) During measurement it is also observed that along with the length of wear on the flank face the width of wear is also greater in case of dry machining. There is built-up-edge formation in case of dry machining.
3) While the tool wear is compared in dry and MQL condition the average tool wear observed in MQL condition is 46.75 µm whereas in case of dry machining the average tool wear is 72.22 µm. Tool wear is 35.25 % lesser in case of MQL machining.

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