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Analysis of Minimum Quantity Lubrication on Tool Wear for Incoloy-800 during Turning Operation

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Abstract: The growing demands for high productivity of machining need use of high cutting velocity and feed rate. Such machining inherently produces high cutting temperature, which not only reduces tool life but also impairs the product quality. Application of cutting fluids changes the performance of machining operations because of their lubrication, cooling, and chip flushing functions. But the conventional cutting fluids are not that effective in such high production machining. Minimum quantity lubrication (MQL) presents itself as a viable alternative for turning with respect to tool wear, heat dissipation, and machined surface quality. This study compares the mechanical performance of MQL to completely dry and flood lubrication for the turning of INCOLOY 800 based on experimental measurement of tool wear. Results indicates that the use of MQL leads to lower tool wear as compared to dry and flood lubrication.

Keywords- S/N ratio, ANOVA, Multiple Regression Model.

1.INRODUCTION

INCOLOY 800 series of alloys, invented by the Special Metals Corporation Group of Companies, is the result of years of monitoring and maintaining the ultimate chemical properties for high-temperature strength and resistance to oxidation, carburization and other types of high-temperature corrosion Each one a refinement of the one before, these alloys have set the industry standard in high-temperature applications requiring optimum creep & rupture properties. INCOLOY-800 nickel-iron-chromiumalloy was introduced to the market in the 1950s to fill the need for a heat- and corrosion-resistant alloy with relatively low nickel content since nickel was, at the time, designated a “strategic” metal. Over the past forty years it has been widely used for its strength at high temperatures and its ability to resist oxidation, carburization, and other types of high-temperature corrosion. Applications include furnace components and equipment, petrochemical furnacecracker tubes, pigtails and headers, and sheathing for electrical heating. Due to its high temperature corrosion resistance and excellent high temperature strength up to 815°C, combined with ease of fabrication and weld-ability, the Nicrofer C 263 alloy finds a wide range of applications in high-temperature service, especially in aircraft and industrial gas turbines. Examples are combustion chambers, exhaust cones and rings. Metal cutting or simplymachining, is one of the oldest processes for shaping components in the manufacturing industry. It is estimated that 15% of the value of all the mechanical components manufactured worldwide is derived from machining operations. To remain in business manufacturing companies have to machine the components at required quality with minimum possible cost and hence the life of cutting tool becomes utmost important aspect for manufacturing engineers and researcher. There are numbers of reasons for Tool failure. The unavoidable reason is gradual wear which is the result of interaction between work and tool. Tool wear and breakage has been an issue with cutting tools since they were created. Tool wear weakens the cutting tool, increases the forces used in cutting and causes a lack of consistency in material removal. Parts and time lost to scrap and rework from tool wear are costly to manufacturing companies. Under high temperature, high pressure, high sliding velocity and mechanical or thermal shock in cutting area, cutting tool has normally complex wear appearance, which consists of some basic wear types such as crater wear, flank wear, thermal crack, brittle crack, fatigue crack, insert breakage, plastic deformation and Build-up Edge. The dominating basic wear types vary with the change of cutting conditions.

2. LITERATURE

C. Remino et al. 2005: This paper describes the effect of MQL on tool wear during turning Normalized 100Cr6 steel. It is found that lubricating the rake surface of a tip by the MQL technique does not produce evident wear reduction. Tool life time of a tip used in dry cutting conditions is similar to that of a tip lubricated by MQL on the rake. Lubricating the flank surface of a tip by the MQL technique reduces the tool wear and increases the tool life. Traces of lubricant compounds have been found on the worn surfaces only when MQL has been applied on the flank surface. M.W. Islam et al. 2007: In this the paper the effect of effects of MQL on tool wear, Job Dimension and Finish in Turning AISI-1040 Steel is studied. The cutting performance of MQL machining is better than that of conventional machining with flood cutting fluid supply. The most significant contribution of application of MQL in machining the steel by the carbide insert undertaken has been the high reduction in flank wears, which would enable remarkable improvement in tool life. Such reduction in tool wear might have been possible for retardation of abrasion and notching, decrease or prevention of adhesion and diffusion type thermal sensitive wear at the flanks and reduction of built-up edge (BUE) formation which accelerates wear at the cutting edges by chipping and flaking. Deep notching and grooving, which are very detrimental and may cause premature and catastrophic failure of the cutting tools, are remarkably reduced by MQL.S.Hasan et al. 2009:A study of minimum quantity lubrication on Inconel 718 steel is conducted during milling. It is found that MQL technique offer better results than by dry cutting in terms of surface roughness. The total length of travel by super cobalt cutting tool in MQL condition is higher than that in dry cutting. The end milling process of Inconel 718 with cutting speed of 10 m/min and 20 m/min results in worse machining characteristics both in dry and MQL milling. MQL does not contribute any significant results when milling with low cutting speeds. Super alloy tools show good performance on surface roughness at 30 m/min by MQL than dry milling. There was improvement in surface roughness at 37.5 ml/ hour MQL supply than 12.5 and 25 ml per hour. The flank wear by 37.5 ml / hour by MQL was low. The tool life was increased by 43.75 % by MQL than dry cutting. L.B.Abhang et al. 2010 :In the paper 10% boric acid by weight mixed with base oil\SAE 40 is used as a MQL in turning process. Variations in cutting (lubricant) force, cutting temp, chip thickness and surface roughness are studied under different machining conditions. The results indicate that there is a considerable improvement in machining performance with MQL assisted machining compared to dry machining. Minimum quantity lubricant reduced the cutting forces by about 5 % to 12% favourable change in the chip-tool interaction and retention of cutting edge sharpness due to reduction of cutting zone temperature seemed to be the main reason behind reduction of cutting forces by the minimum quantity of lubrication. It reduces chip thickness up to 12 to 17% over dry turning that is also favourable for chip formation in compare to dry machining. Surface finish also significantly improved mainly due to significant reduction wear and damage at the tool tip by the application of minimum quantity lubricant. TadeuszLeppert 2011: In this paper the effects of cooling and lubrication on tool wear in turning 316L steel is investigated. It is found that there is a significant influence of the cooling and lubrication conditions on the tool wear. Turning dry or with MQL increases tool wear. The application of mql compared to turning with emulsion facilitates elimination or considerable reduction of machined material adhesion to the tool surfaces. S.R.Das et al. 2012: This paper presents an optimization method of the cutting parameters (cutting speed, depth of cut and feed) in dry turning of AISI D2 steel to achieve minimum tool wear and low work piece surface temperature. The experimental layout was designed based on the Taguchi’s L9 Orthogonal array technique and analysis of variance (ANOVA) was performed to identify the effect of the cutting parameters on the response variables. The results showed that depth of cut and cutting speed are the most important parameter influencing the tool wear. The minimum tool wear was found at cutting speed of150 m/min, depth of cut of 0.5 mm and feed of 0.25 mm/rev .Similarly low work piece surface temperature was obtained at cutting speed of 150 m/min, depth of cut of 0.5 mm and feed of0.25 mm/rev.Thereafter, optimal ranges of tool wear and work piece surface temperature values were predicted. Finally, the relationship between factors and the performance measures were developed by using multiple regression analysis.

3. EXPERIMENTATION

3.1 Experimental Design

To select an appropriate orthogonal array for the experiments, the total degrees of freedom need to be computed. The degrees of freedom are defined as the number of comparisons between design parameters that need to be made to determine which level is better and specifically how much better it is. L9 array is used to conduct experiment.

3.2 Work piece Material

INCOLOY 800 series of alloys, invented by the Special Metals Corporation Group of Companies, is the result of years of monitoring and maintaining the ultimate chemical properties for high-temperature strength and resistance to oxidation, carburization and other types of high-temperature corrosion Each one a refinement of the one before, these alloys have set the industry standard in high-temperature applications requiring optimum creep and rupture properties.

Table 3.4: chemical composition of INCOLOY 800

METAL	PERCENTAGE
C	0.039 %
Si	0.369 %
Mn	1.020 %
Ni	31.12 %
Cr	20.09 %
S	0.011 %
Cu	0.360 %
Al	0.220 %
Ti	0.310 %

3.3 Machine Tool

For the present experimental studies, an EN8 Steel is machined using Uncoated CARBIDE cutting tools on a Lathe machine at different speed-feed-depth of cut combinations under, dry condition, minimum quantity lubrication (MQL) condition and flood condition to study the role of MQL on the tool wear. The ranges of the cutting velocity, feed rate and depth of cut were selected based on the tool manufacturer's recommendation and industrial practices.

Table I. Experimental conditions:

Machine tool	**GEDEE WIELER**
Work piece	INCOLOY 800(dia 32mm)
Cutting tool	UNCOATED CARBIDE INSERTS
Insert code system	CNMG120408-FG
Cutting velocity, Vc	40,50 and 60m/min
Feed rate, f:	0.033,0.066 and 0.132mm/rev
Depth of cut, d:	0.5,0.75 and 1mm
MQL supply:	Air:2 bar, Dry, Mql1(150ml/hr), Mql2(300ml/hr Flood(600ml/hr)

Table II: Machine Specifications:

Specification	Value
Model	LZ 300 G
Distance Between Centres	800 mm
Swing Around The Bed	300 mm
Spindle Variable Speeds	45 – 2500 rpm

Table III. Air Compressor Specification

Specification	Value
Model	140 TC 0.5
Motor H.P	0.5
Displacement	80 ltr/min
Max.Working Pressure	4 kg/cm^2
Unit R.P.M	700
Tank Capacity	40 ltr

3.4 Cutting Fluids

The cutting fluids produce three positive effects in the process: heat removal elimination, lubrication on the chip–tool interface and chip removal.

Table IV: Properties of cutting fluid

Physical State	Low viscous oil
Viscosity	0.04914 kg $m^{-1}s^{-1}$
Odour	Neutral
Appearance	Pale yellow
Flashpoint	Greater than 250°C

Figure 3.1 Vegetable oil

3.5 Tool Wear Measurement

Table V: Properties of Tool Maker

Optical axis	30°
Cross hair reticule	supplied
Eye piece magnification	15×
Objective magnification	2×
Dimensions	152×152mm
Maximum height	115mm
Light source	24V, 2W
Green filter	supplied.

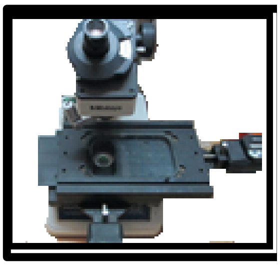

Figure 3.2 Tool maker's microscope

4. RESULTS AND DISCUSSION

4.1 S/N Response Tables

4.1.1 S/N responses for tool wear (Dry Condition)

The effects of cutting parameters on tool wear are measured at dry condition and the trends are shown in Fig.4.1.Here as cutting velocity increases from 40 m/min to 60 m/min S/N for tool wear reduces drastically and as feed increases from 0.033 mm/rev to 0.132 S/N for tool wear first decrease and then increases.

Table VI:

Level	1	2	3	Delta(Max.-Min)	Rank
Speed	16.96	15.78	14.68	2.16	1
Feed	15.92	15.66	15.84	0.25	3
Depth of cut	15.86	16.36	15.19	1.12	2

4.1.2 S/N responses for Tool wear (Mql1 Condition)

The effects of cutting parameters on tool wear are measured at Mql1condition and the trends are shown in Fig.4.2.Here as cutting velocity increases from 40 m/min to 60 m/min S/N for tool wear reduces drastically and as feed increases from 0.033 mm/rev to 0.132 S/N for tool wear first decrease and then increases. Whereas when DOC varies from 0.5 mm to 1mm S/N for tool wear decreases.

Table VII:

Level	1	2	3	Delta(Max.-Min)	Rank
Speed	17.82	16.69	15.55	2.27	1
Feed	16.76	16.53	16.77	0.24	3
Depth of cut	17.25	16.67	16.15	1.10	2

4.1.3 S/N responses for Tool wear (Mql2 Condition)

The effects of cutting parameters on tool wear are measured at Mql2 condition and the trends are shown in Fig.4.3.Here as cutting velocity increases from 40 m/min to 60 m/min S/N for tool wear reduces drastically and as feed increases from 0.033 mm/rev to 0.132 S/N for tool wear first decrease and then increases. Whereas when DOC varies from 0.5 mm to 1mm S/N for tool wear decreases.

Table VIII:

Level	**1**	**2**	**3**	**Delta(Max.-Min)**	**Rank**
Speed	17.94	16.83	15.69	2.24	1
Feed	16.89	16.63	16.93	0.31	3
Depth of cut	17.37	16.77	16.32	1.05	2

4.1.4 S/N responses for Tool wear (Flood Condition)

The effects of cutting parameters on tool wear are measured at Flood condition and the trends are shown in Fig.4.4.Here as cutting velocity increases from 40 m/min to 60 m/min S/N for tool wear reduces drastically and as feed increases from 0.033 mm/rev to 0.132 S/N for tool wear first decrease and then increases. Whereas when DOC varies from 0.5 mm to 1mm S/N for tool wear decreases.

Table IX:

Level	**1**	**2**	**3**	**Delta(Max.-Min)**	**Rank**
Speed	17.69	16.49	15.38	2.31	1
Feed	16.49	16.38	16.55	0.25	3
Depth of cut	17.08	16.50	15.98	1.10	2

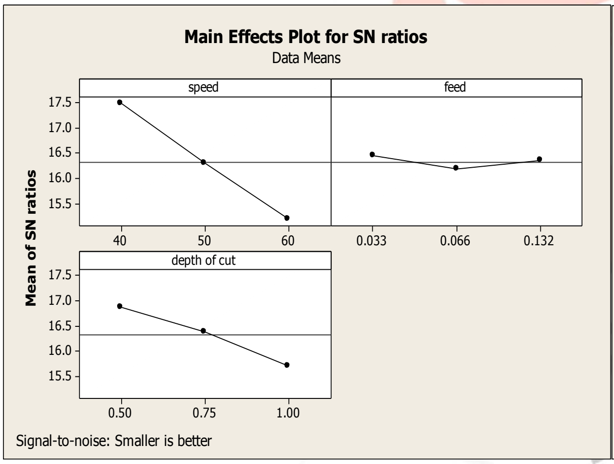

Figure 4.1 Main Effects plot for Tool wear (Dry Condition)

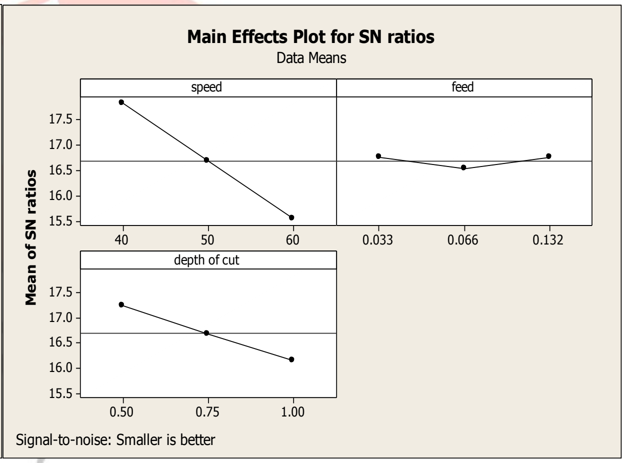

Figure 4.2 Main Effects plot for Tool wear (Mql1 Condition

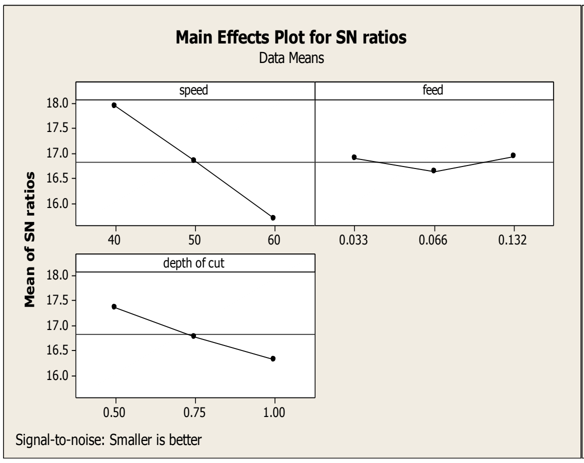

Figure 4.3Main Effects plot for Tool wear (Mql2 Condition)

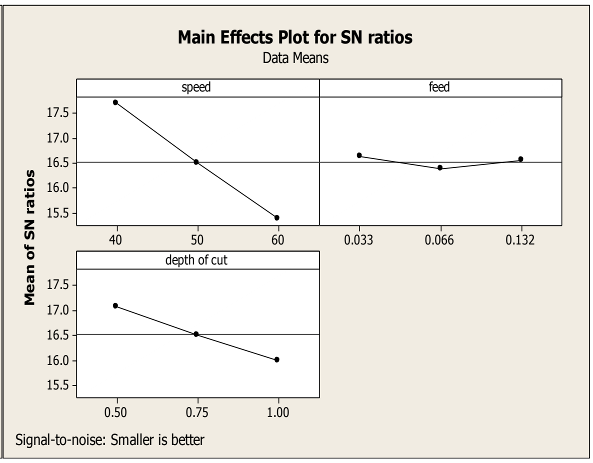

Figure4.4 Main Effects plot for Tool wear (Flood Condition)

4.2 ANOVA Results

Table X: ANOVA Results for Tool wear (Dry Condition)

Source	DF	Seq SS	Adj MS	F	P	Contribution %
Speed	2	0.0024009	0.0012004	2701.00	0.000	78.62
Feed	2	0.0000222	0.0000111	25.00	0.038	0.72
Depth of cut	2	0.0006296	0.0003148	708.25	0.001	20.61
Error	2	0.0000009	0.0000004			
Total	8	0.0030536				

S = 0.000666667   R-Sq = 99.97%   R-Sq(adj) = 99.88%

It can be observed that cutting velocity is the most significant factor affecting the tool wear contributing 80.65% to the total effect.

Table XI: ANOVA Results for Tool wear (Mql1 Condition):

Source	DF	Seq SS	Adj MS	F	P	Contribution %
Speed	2	0.0022069	0.0011034	9931.00	0.000	80.65
Feed	2	0.0000249	0.0000124	112.00	0.009	0.91
Depth of cut	2	0.0005042	0.0002521	2269.00	0.000	18.42
Error	2	0.0000002	0.0000001			
Total	8	0.0027362				

S = 0.000333333   R-Sq = 99.99%   R-Sq(adj) = 99.97%

It can be observed that cutting velocity is the most significant factor affecting the tool wear contributing 80.99% to the total effect.

Table XII: ANOVA Results for Tool wear (Mql2 Condition):

Source	DF	Seq SS	Adj MS	F	P	Contribution %
Speed	2	0.0020942	0.0010471	2356.00	0.000	80.99
Feed	2	0.0000389	0.0000194	43.75	0.022	1.5
Depth of cut	2	0.0004516	0.0002258	508.00	0.002	17.46
Error	2	0.0000009	0.0000004			
Total	8	0.0025856				

S = 0.000666667   R-Sq = 99.97%   R-Sq(adj) = 99.86%

It can be observed that cutting velocity is the most significant factor affecting the tool wear contributing 81.34% to the total effect.

Table XIII: ANOVA Results for Tool wear (Flood Condition)

Source	DF	Seq SS	Adj MS	F	P	Contribution %
Speed	2	0.0023607	0.0011803	3541.00	0.000	81.34
Feed	2	0.0000180	0.0000090	27.00	0.036	0.62
Depth of cut	2	0.0005227	0.0002613	784.00	0.001	18.01
Error	2	0.0000007	0.0000003			
Total	8	0.0029020				

S = 0.000577350   R-Sq = 99.98%   R-Sq(adj) = 99.91%

It can be observed that cutting velocity is the most significant factor affecting the tool wear contributing 81.34% to the total effect.

Table XIV: Optimum Conditions for Tool Wear

S.No	Cutting Condition	Predicted Tool Wear	Experimental Tool Wear	%Error
1	Dry	0.124	0.128	3.22
2	MQL1	0.120	0.122	1.66
3	MQL2	0.116	0.119	2.58
4	Flood	0.118	0.124	5.08

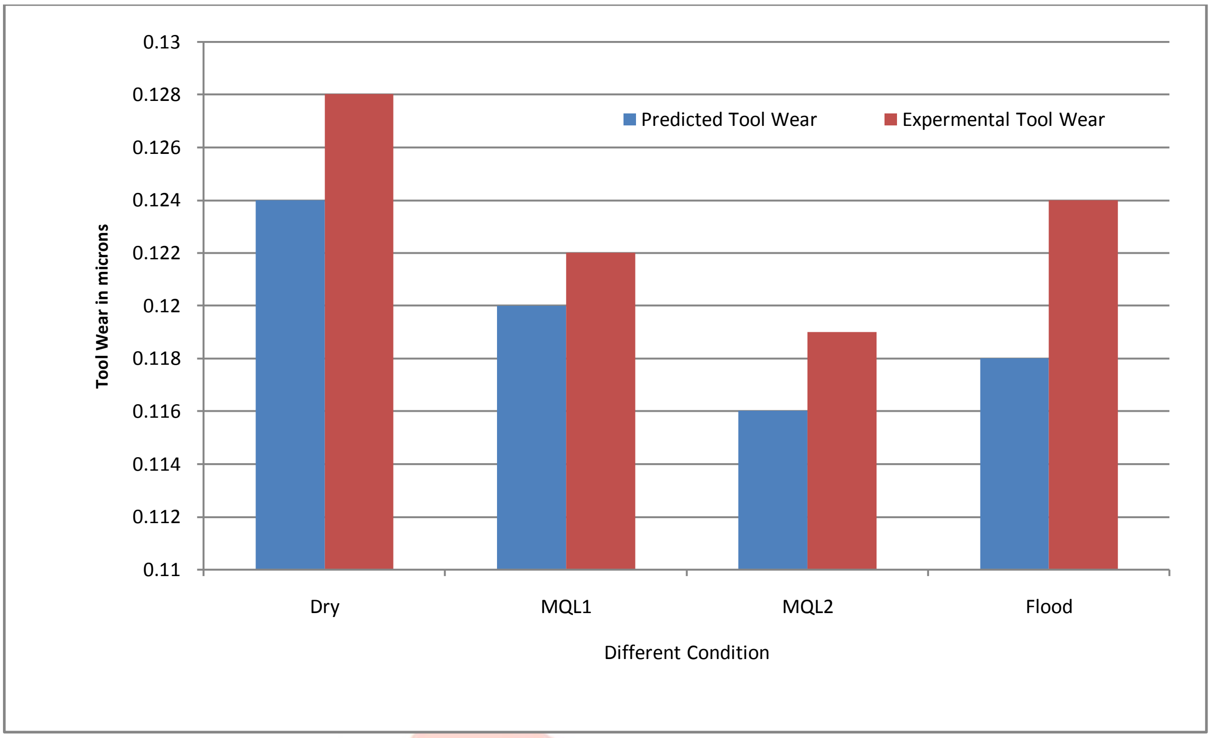

Figure 4.5 Comparison of Predicted vs. Actual

The tool wear is less under MOL2 and maximum in dry condition as shown in figure 4.5.

4.4 Regression Equation General Regression Analysis- Tool wear (T_w) versus Speed(S), Feed (F), Depth of cut(D)

4.4.1Under Dry Condition:

$$T_w = 0.0720581 + 0.0406667 \times D + 1.99557 \times 10^{-6} \times S^2 \cdots\cdots\cdots\cdots Eq(1)$$

4.4.2 Under MQL1 Condition:

$$T_w = 0.070814+0.0366667 \times D+1.91417 \times 10^{-5} \times S^2 \cdots\cdots\cdots Eq(2)$$

4.4.3 Under MQL2 Condition:

$$T_w = 0.0713566 + 0.0346667 \times D + 1.8648910^{-5} \times S_2 \cdots Eq(3)$$

4.4.4 Under Flood Condition:

$$T_w = 0.0414798 + 0.126 \times D - 0.00135049 \times S \times D + 2.63899 \times 10^{-5} \times S^2 + 0.00290899 \times S \times F - 0.241326 \times F \times D \cdots\cdots\cdots\cdots\cdots\cdots Eq(4)$$

5. CONCLUSIONS

From the results obtained during the experimental investigations on machining INCOLOY 800 using uncoated carbide tools with Dry, Mql1, Mql2 and Flood as the cooling and lubricating media at different cutting speed, feed and depth of cut combinations, the conclusions can be made as follows

- Taguchi’s robust orthogonal array design method is suitable to analyze the tool wear during the present operation. It is found that the parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for the optimization of the cutting parameters.
- The cutting performance of MQL machining is better than that of conventional dry and flood machining.
- It is clear from the results that the performance of the MQL technique is greatly enhanced at low cutting speeds, feeds and depth of cuts. As we move to high cutting speeds, Feeds and depth of cuts the pulsed jet can’t be able to travel to the machining zone effectively and there by its performance is declined.
- The experimental results demonstrate that the Speed is the main parameter among the three controllable factors (cutting speed, feed rate and depth of cut) that influence the tool wear in machining INCOLOY 800.
- It has been shown that tool wear can be reduced for Machining INCOLOY 800 under the condition of MQL condition as compared to Dry and Flood condition
- MQL is a technique that could reduce many cutting problems coming from high consumptions of lubricant, like high machining costs or environmental and health problems
- Model generated in Dry, MQL1,MQL2 and Flood conditions are acceptable.

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