

# Machining Performance Evaluation of Liquid Nitrogen Treated M2 Cutting Tools for Turning Operations

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*The present study is focused on liquid nitrogen treatment of M2 tool steel for 12 hours, 24 hours, and 36 hours at  $-196^{\circ}\text{C}$  followed by tempering at  $150^{\circ}\text{C}$ . The treated tool samples are used for machining low carbon steel on a CNC lathe to varying combinations of Spindle speed (700, 1100 & 1800 rpm), Feed rate (0.1, 0.125 & 0.15 rev/mm) and Depth of cut (0.15, 0.3 & 0.45 mm). Taguchi's Design of experiments and ANOVA methods are used to statistically analyze the effect of cutting parameters and cutting forces on the tool wear and surface roughness after experimentation. SEM analysis is carried out to investigate the type of tool wear experienced by the cutting tools. The regression analysis has resulted in a model to predict the values of surface roughness, tool wear and friction coefficient, with a maximum error of  $\pm 6\%$  from the actual experimental values.*

**Keywords:** Liquid nitrogen treatment, surface roughness, tool wear, flank wear, Taguchi, ANOVA.

## 1. INTRODUCTION

The life of cutting tools is one of the important factors which affect the production rate in the manufacturing industry. The major problem in the cutting tools during functional are tip wear and sudden failure due to the vibrations occurred, which affects the life and increases the production cost [1]. These failures can be reduced by improving the internal properties of the cutting tool materials. Currently, the materials are subjected to heat treatment followed by tempering to improve the properties of cutting tool material. Researchers have absorbed the fact that the existence of retained austenite, which is soft and unstable at low temperatures and becomes fragile during machining, is one of the main factor causing sudden failure of the cutting tool [2].

Currently, the study on Liquid nitrogen Treatment - LNT to improve the properties of cutting tool materials is a general topic between researchers. LNT is an additional step after the heat treatment method and it is a one-time treatment in which the retained austenite is converted into martensite [3]. Properties such as Tensile strength [4], Hardness [5], fatigue behaviour [6] and wear resistance [7-9] were found to be increasing by the various researcher. Similarly, cryogenic treatment was used to enrich the lives of many commercial and industrial materials [10]. Cryogenic treatment features a wide selection of applications such as Machining, electronic, automotive materials, food process, health and aviation [10-12]. The Temperature between  $-80$  to  $-140^{\circ}\text{C}$  is known as Shallow cryogenic treatment - SCT and  $-140$  and  $-196^{\circ}\text{C}$  is known as Liquid nitrogen treatment- LNT [13]. The treatment generally includes cooling down the cutting tools below subzero temperature, using liquid nitrogen, at

a constant rate of cooling to avoid the distortion due to thermal shock damages. Cutting tools are retained at the desired temperature for a specific interval of time before bringing back to ambient temperature [14]. Ramji et al assessed surface finish by conducting the drilling operation of gray cast iron using Cryo-treated HSS drill and achieved substantial improvements in the surface finish after cryogenic treatment [15]. Reddy et al. evaluated the tool wear and surface finish of C45 steel and found that the tool wear of Cryotreated tool was minimum when compared with the untreated tool. Also noticed the decrease in the surface finish value with increased Spindle Speed for Cryotreated tool [16].

The influence of Liquid Nitrogen treatment on tool wear and life of M2 drills was studied by Firouxdor et al. [17]. The result obtained specified the rise in tool life after cryo-treatment which was due to the conversion of retained austenite to martensite and uniform distribution of carbides. Similar research was done by Cicek et al. [18], he carried out the study using M35 Cryo-treated twist drill for machining 316 stainless steel. The results indicated a 218% increase in the tool life. Thrust force and surface roughness were also found to be better in case of liquid nitrogen treated tools. Enhancement of results was mainly due to the change in retained austenite to martensite. Podgornik et al. [19] in their research work found that tool composition and type of tool plays a very vital role in the results that are obtained from by cryogenic treatment. Asiltürk et al [20] Used Taguchi approach to optimize the parameter of turning. The experiment was conducted with L9 orthogonal array and the surface roughness of AISI 4140 steel was chosen as the response parameter. The findings showed that the feed rate was the most significant parameter for surface roughness. Sahin [21] by using the Taguchi method, the tool life of CBN and ceramic inserts was compared when turning hard steels. Also, ANOVA was used to determine the impact of cutting parameters on tool life. As a result, the impact on tool life of Spindle Speed, tool hardness and feed rate was found to be 41.63%, 32.68% and 25.22% respectively.

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Based on the above study, the performance of Liquid nitrogen treatment of tools in comparison with heat-treated and untreated was found to be improving due to its microstructural changes after the cryogenic treatment [22, 23]. Certainly, investigations required for holding time during the treatment is found to be inadequate. In this perspective, the present study is being carried out to evaluate the performance during turning of low carbon steel at different cutting parameters such as Spindle Speed, feed and depth of cut using Liquid Nitrogen-treated M2 tool steel. Liquid Nitrogen-treatment of M2 Tools was carried out at 12 hours, 24 hours, 36 hours holding time followed by tempering at 150 °C. The tool wear, cutting forces and surface roughness are analyzed during the turning process. The tests were conducted using Taguchi technique to find the optimum values. Finally, using SEM and EDAX analysis, the wear mechanism of the cryo-treated tools was evaluated.

## 2. MATERIALS AND PROCEDURE

### 2.1 Material for Work piece

Low carbon steel with carbon percentage 0.19 % is selected for carrying out the turning experiments as it is the most commonly and widely used type of steel in industrial applications. Low carbon steel, commonly known as mild steel makes itself compatible for variety of applications because of physical and economical aspects. Low carbon steel having measurements of 250 mm length and 40 mm diameter was used for turning study. The chemical properties of low carbon steel are shown in Table 1.

**Table 1: Chemical analysis results of low carbon steel.**

Sr No	Content	Percent (%)
1	C	0.19
2	Fe	98.84
3	Mn	0.85
4	P	<0.030
5	S	<0.043

### 2.2 Cutting Tool Material

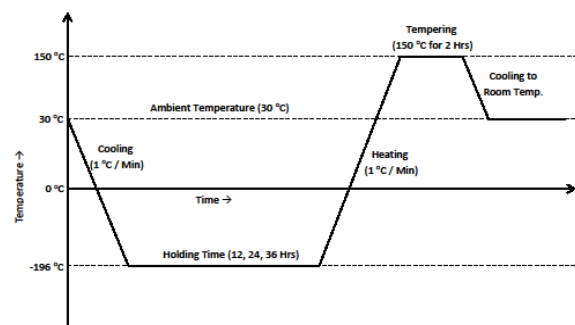
In the present study, a Liquid Nitrogen-treated single point cutting tool of AISI M2 tool steel having dimensions 12×12×80 mm is used. The treatment was carried out for 12 hours, 24 hours, 36 hours holding time. The tool geometry was prepared as per ISO grade: Side rake angle of 4°, Side cutting edge angle of 30°, End relief angle of 8°, Back rake angle of 14° and Nose radius = 0.4 mm. The chemical composition of the M2 tool steel is as in Table 3.

**Table 2: Chemical analysis results showing the proportion of alloys in M2 tool steel**

Sr No	Content	Percent (%)
1	W	6.404
2	V	1.912
3	Mo	4.549
4	Cr	4.19
5	S	0.022
6	P	0.028
7	Mn	0.241
8	Si	0.262
9	C	0.864

### 2.3 Liquid nitrogen Treatment

Primarily, the single point cutting tools were subjected heat treatment process at an austenitizing temperature in the vacuum furnace and later quenching of specimens via Oil and air to bring back the tools to room temperature. The heat-treated samples were then subjected to liquid nitrogen for the Liquid Nitrogen-treatment process at -196 °C at 1 °C/min cooling rate. The treatment was carried out at 12 hours, 24 hours and 36 hours holding time. The complete process was supported by a controlled chamber. Quickly after the Liquid Nitrogen-treatment, the tools were subjected to tempering at 200 °C for 2 hours. The samples were then designated based on the cryogenic soaking hour as LN-12 for 12 hours, LN-24 for 24 hours and LN-36 for 36 hours holding time. Figure. 1 depicts the Liquid Nitrogen-treatment cycle for AISI M2 steel.



**Figure 1. Liquid Nitrogen-Treatment Cycle.**

### 2.3 Setup Used for Experimentation

The turning study was carried out on CNC (Computer numerically controlled) HAAS make (GT-10) turning machine. Cutting force, Tool wear and surface roughness were selected as the response study. The cutting forces were evaluated during the turning process using the lathe tool dynamometer based on the microcontroller. For statistical analysis, the resulting force  $F$  calculated using Equation (1) is regarded. For each experiment with a set cutting moment of 5.0 min, the fresh cutting tool was used. At each condition, the tests were performed twice to maintain minimum errors. The RTM-500 (Radical) instrument manufacturer's microscope was used to assess the tool flank wear. The surface roughness ( $R_a$ ) was evaluated on the machined surface at three distinct places using SurfTest-10 (Matrix) surface roughness tester at a cutting length of 0.08 mm at ambient temperature as per ANSI B46.1 standard. The dry turning process flow is as shown in Figure. 2.

$$F_M = \sqrt{f_c^2 + f_f^2 + f_t^2} \quad (1)$$

where  $F_M$  = Mean force

$F_c$  = cutting force

$F_f$  = feed force

$F_t$  = thrust force [26]

Taguchi's L27 orthogonal array was considered for experimentation. The software MINITAB-16 was used to analyze output reactions such as surface roughness,

wear of tools and cutting power. The S / N ratio was calculated using 'lower the better' as provided in the equation 2 for all output response [24].

$$\frac{S}{N} = -10 \log \frac{1}{n} (\sum y^2) \quad (2)$$

### 3. RESULTS AND DISCUSSION:

#### 3.1 Microhardness

Microhardness tests were carried out on OmniTech (MVH-II) Microhardness tester as per ASTM E384–17 standards with a load of about 1000 grams and dwell time of 30 Sec. The average of three values was considered as final Microhardness value. The effect of microhardness values of AISI M2 tool steel can be found from figure 3 with LN at different holding time. The hardness tends to increase of about 65% after LN when compared with untreated specimens. It is observed that with an increase in holding time from LN-12 to LN-24 hours a slight increase in the hardness value was found. The increase in hardness value was found to be marginal of about 10.47% for LN-24 hours holding time when compared with LN-12 hours. It is due to the phase transformation where the retained austenite is converted into martensite and distribution of finer carbide structure in the matrix [25]. Further, as the holding time was varied from LN-24 hours to LN-36 hours there was a drop in the hardness of about 4.26% when compared to LN-24 hours holding time. The drop in the value is due to the dislocation of the carbides in the tempered martensite structure for M2 tool steel [4].

#### 3.2 Turning Study

Turning study experiments of cryogenically treated tool steel for different holding time was conducted based on the design of experiments. Based on the number of factors and their levels, L27 (3<sup>13</sup>) orthogonal array was selected for experiments [25, 27]. The analysis of the experimental values was carried out using MINITAB 16 software. The S-N Ratio calculated using Taguchi's 'smaller the better' quality characteristic for all output response as shown in table 3. ANOVA analysis was also carried out table 4, 5 and 6 illustrate the process parameters with F values and p-values for tool wear, surface roughness and cutting forces. The 95% confidence interval and  $\alpha = 0.05$  significance level were selected for the analysis. The last column of the tables shows the % contribution (P) of each variable. The % contribution was calculated by equation 3.

$$P\% = \text{seq SS} / \text{seq ST} \quad (3)$$

##### 3.2.1 Effect on tool wear

The tool wear was measured by measuring the flank wear using 'Tool maker's microscope'. Table 3 shows the tool wear for 27 different parameter combinations suggested by Taguchi's L-27 array. The table shows that minimum tool wear of 0.055 mm was obtained at LN-24 hours of holding time and maximum tool wear of 0.209 mm was obtained at LN-12 hours holding time. The optimum process parameters observed for minimum tool wear were, 'Spindle Speed' 700 rpm, 'feed' 0.125 mm and 'depth of cut' 0.15 mm. It was also

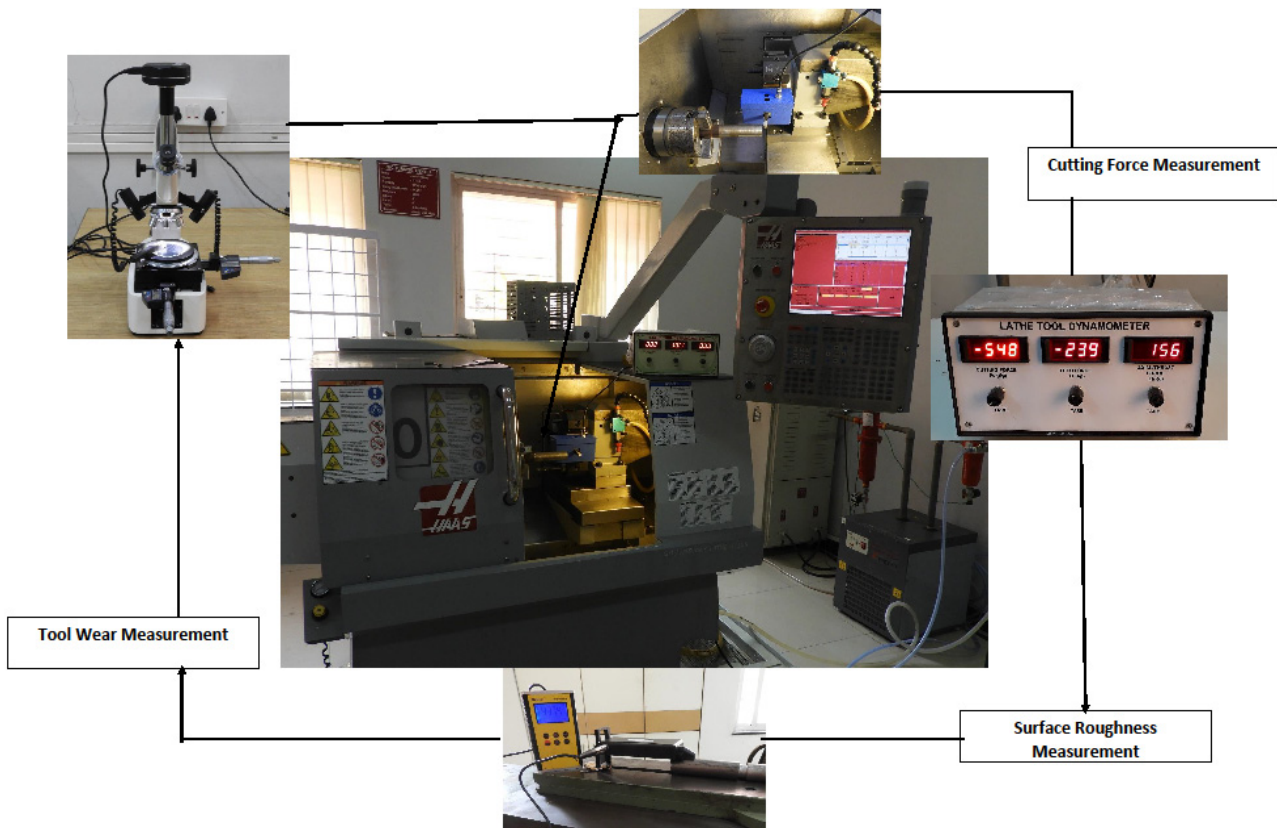
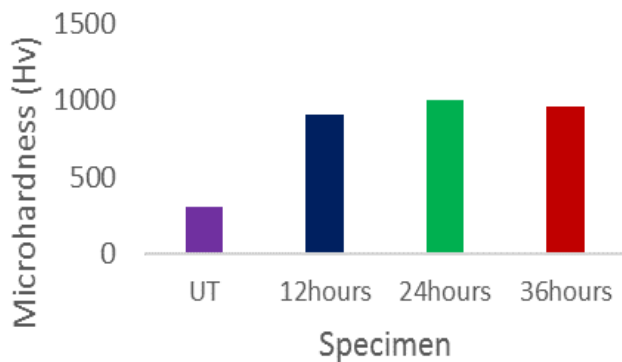


Figure 2: Dry Turning – Output response measurement flow

**Table 3: Experimental results for measuring performance according to the layout of Taguchi (L27)**

Sl.no	T (Hours)	Vc (RPM)	F (mm/rev)	D (mm)	VB max (mm)	S-N Ratio	Ra(μm)	S-N Ratio	CF (Kgf)	S-N Ratio
1	12	700	0.1	0.15	0.086	21.31003	2.733333	-8.73385	21.04757	-28.5552
2	12	700	0.125	0.3	0.209	13.59707	2.9	-9.54243	24.5153	-28.657
3	12	700	0.15	0.45	0.156	16.13751	3.566667	-10.9637	30.38092	-29.8318
4	24	1100	0.1	0.15	0.082	21.72372	2.1	-6.0206	19.0263	-26.7578
5	24	1100	0.125	0.3	0.081	21.8303	2.666667	-8.41012	21.93171	-25.563
6	24	1100	0.15	0.45	0.135	17.39332	2.953333	-9.30766	28.08914	-27.7379
7	36	1800	0.1	0.15	0.117	18.63628	2.266667	-7.23456	22.84732	-26.6652
8	36	1800	0.125	0.3	0.158	16.02686	2.466667	-7.72403	28.4605	-26.9636
9	36	1800	0.15	0.45	0.18	14.89455	2.9	-9.04595	30.74085	-28.0889
10	24	1800	0.1	0.3	0.105	19.57621	2.2	-6.97907	21.77154	-24.7567
11	24	1800	0.125	0.45	0.135	17.39332	2.533333	-8.18739	26.09598	-27.2673
12	24	1800	0.15	0.15	0.125	18.0618	2.433333	-8.07385	23.43075	-26.0746
13	36	700	0.1	0.3	0.131	17.65457	2.366667	-7.35954	29.06888	-27.4663
14	36	700	0.125	0.45	0.133	17.52297	3	-9.34723	32.4037	-29.7864
15	36	700	0.15	0.15	0.086	21.31003	3.1	-9.54243	31.20897	-28.1224
16	12	1100	0.1	0.3	0.129	17.78821	2.933333	-9.14754	21.77154	-27.4586
17	12	1100	0.125	0.45	0.162	15.8097	3.233333	-9.92013	25.19921	-29.1275
18	12	1100	0.15	0.15	0.154	16.24959	2.666667	-8.29947	22.09072	-28.5552
19	36	1100	0.1	0.45	0.127	17.92393	3.033333	-8.62728	27.74887	-27.0757
20	36	1100	0.125	0.15	0.095	20.44553	2.833333	-8.83914	26.83282	-25.2244
21	36	1100	0.15	0.3	0.13	17.72113	2.933333	-9.10705	29.06888	-28.1757
22	12	1800	0.1	0.45	0.185	14.65657	2.5	-7.72403	23.04344	-28.5552
23	12	1800	0.125	0.15	0.12	18.41638	2.766667	-8.73385	17.72005	-27.1767
24	12	1800	0.15	0.3	0.185	14.65657	3.133333	-9.92013	22.02272	-28.1757
25	24	700	0.1	0.45	0.086	21.31003	2.6	-8.41012	29.69848	-27.5435
26	24	700	0.125	0.15	0.055	25.19275	2.766667	-8.83914	27.38613	-26.2118
27	24	700	0.15	0.3	0.082	21.72372	2.833333	-9.04595	30.03331	-28.9042

observed that the range of tool wear for LN-12 hours of holding time was 0.086 mm to 0.209 mm, the range of tool wear for LN-24 hours was 0.055 mm to 0.135 mm and the range of tool wear for LN-36 hours was also 0.086 mm to 0.18 mm. It was observed that the overall range of tool wear for LN-24 hours holding time shows minimum tool wear compare to LN-12 and LN-36 hours of holding time.



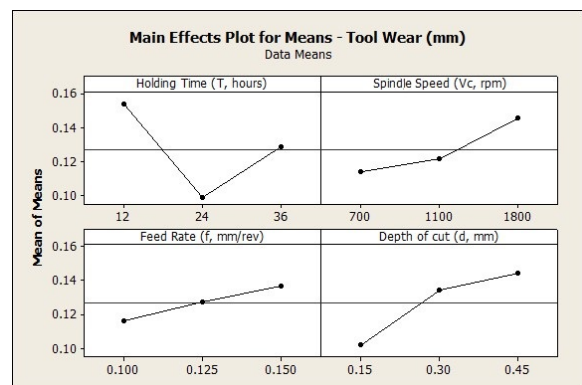
**Figure 3. Microhardness results of M2 tool steel**

Significant parameter for tool wear for specimen LN treated with different holding time was identified using ANOVA which can be seen in table 4. Based on the P-value, the percentage contribution in wear by each parameter was calculated. The last column shows the value of % contribution of the variables were holding time contributes the maximum (35.6 %), followed by the depth of cut (23.8%), Spindle Speed (15.4%) and feed (4.5%). The interaction of Spindle Speed and depth of cut (8.47%) is also influencing the tool wear.

**Table 4: Tool Wear - ANOVA**

Source	DF	Seq SS	Adj SS	Adj MS	F	P	P (%)
T	2	71.699	71.699	35.8497	42.27	0.000	35.6
Vc	2	31.125	31.125	15.5624	18.35	0.003	15.4
F	2	8.845	8.845	4.4224	5.21	0.049	4.5
D	2	47.753	47.753	23.8764	28.15	0.001	23.8
Vc*F	4	8.276	8.276	2.0689	2.44	0.158	4.2
Vc*D	4	17.058	17.058	4.2645	5.03	0.040	8.4
F*D	4	11.058	11.058	2.7645	3.26	0.096	5.5
Error	6	5.088	5.088	0.8480			
Total	26	200.902					

S = 0.9209 R-Sq = 97.3% R-Sq(adj) = 91.2%



**Figure 4: Main effect plot – Tool wear**

Figure 4 shows the main effect plot for means of tool wear. Main effect plot shows that tool wear is decreasing as the holding time is increasing from LN-12 to LN-24 hours and later by increasing the holding time the tool wear. So considering the quality characteristics, LN-24 hours observed as optimum holding time. It can be commented that LN-24 hours of holding time refine

the grain structure of tool steel to the extent that it shows maximum resistance to wear. It was also observed that as the speed of the cutting tool increases there is an increase in the tool wear. For variation in the Spindle Speed from 700 to 1800 rpm there is an increase in tool wear from 0.11 to 0.15 mm. Due to high Spindle Speed, there is an increase in the forces generated during machining resulting in increase of the tool wear. For variation in the feed rate of the cutting tool from 0.1 mm/rev to 1.15 mm/rev as the feed increases the point of contact of the cutting tool with the workpiece in a given point of time, which exposes the tool to continuous acting of forces, resulting in deteriorating the tool life. Similar is the case with an increase in depth of cut which increases the surface contact of cutting edge with the workpiece. This results in increasing the temperature between the tool and workpiece due to high friction. Increase in the temperature makes the tool material softer making it more prone to wear and tear.

### 3.2.2 Effect on surface roughness

Table 3 shows the average surface roughness value as per trial conditions. From the table, it can be seen that the surface roughness values are ranging from 2.1  $\mu\text{m}$  to 3.56  $\mu\text{m}$ . During analyzing the Ra values with respect to the soaking temperature, it was observed that for holding time LN-12 hours surface roughness values were varying from 2.5  $\mu\text{m}$  to 3.566  $\mu\text{m}$ , for holding time LN-24 hours surface roughness values were varying from 2.1  $\mu\text{m}$  to 2.953  $\mu\text{m}$ , and for LN-36 hours surface roughness values were varying from 2.266  $\mu\text{m}$  to 3.1  $\mu\text{m}$ . It was observed that the overall range of surface roughness for LN-24 hours holding time shows minimum surface roughness value compared to LN-12 hours and LN-36 hours of holding time.

Table 5: Surface roughness - ANOVA

Source	DF	Seq SS	Adj SS	Adj MS	F	P	P (%)
T	2	6.2716	6.2716	3.1358	21.48	0.002	21.2
Vc	2	4.5349	4.5349	2.2675	15.54	0.004	15.3
F	2	8.6483	8.6483	4.3241	29.63	0.001	29.2
D	2	4.0496	4.0496	2.0248	13.87	0.006	13.7
Vc*F	4	1.4158	1.4158	0.3539	2.42	0.159	4.8
Vc*D	4	2.6325	2.6325	0.6581	4.51	0.051	8.9
F*D	4	1.2031	1.2031	0.3008	2.06	0.205	4.06
Error	6	0.8757	0.8757	0.1460			
Total	26	29.6315					

S = 0.3820 R-Sq = 97.0% R-Sq(adj) = 89.2%

Significant parameter for tool wear for specimens cryo-treated with different holding time was identified using Analysis of variance (ANOVA) which can be seen in table 5. Based on the P-value, the percentage contribution in wear by each parameter was calculated. The last column shows the percentage contribution of all the variables wherein maximum contribution was noticed from feed (29.2%) followed by holding time (21.2%), depth of cut (13.7%), Spindle Speed (15.3%).

It can be seen from the figure 5 that within the scope of this investigation that the surface roughness is decreasing as the holding time is increasing from LN-12 to LN-24 hours and later by increasing the holding time to LN-36 hours the surface roughness is again increasing. So LN-24 hours can be considered as optimum

holding time. It is also observed that as the speed of the cutting tool increases there is a decrease in surface roughness values. For variation in the Spindle Speed from 700 to 1800 rpm there is a decrease in surface roughness from 2.85 to 2.4  $\mu\text{m}$ . The improvement in surface roughness is because of high material removal from the same length of the workpiece, which is a result of the high Spindle Speed of the cutting tool. Lower speed of the cutting tool deteriorates the surface roughness. So higher Spindle Speed is desired for optimum performance for surface roughness, as the feed rate of the cutting tool increases, there is an increase in the average value of surface roughness. For variation in the feed rate of cutting tool from 0.1 mm/rev to 1.15 mm/rev as the feed increases the material removal rate also increases, which deteriorates the surface roughness. So lower feed rate is desired for the achievement of good surface roughness. Similar is the case with an increase in depth of cut. The increase in depth of cut increases the temperature of the tool and workpiece due to high friction between the tool and workpiece, which in turn increases the surface roughness. So minimum depth of cut is preferred during machining.

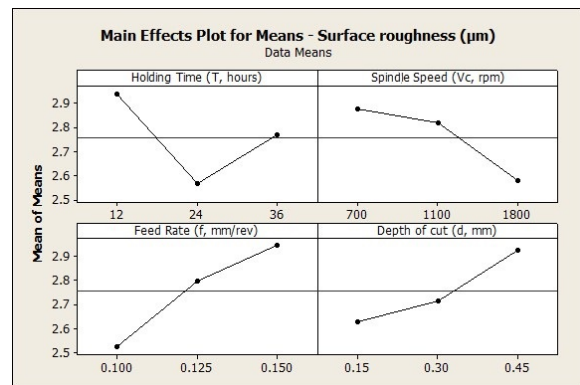


Figure 5: Main effect plot - Surface roughness

### 3.2.3 Effect on cutting forces

Table 3 shows the average cutting force value as per trial conditions. The optimum process parameters observed for minimum cutting forces were, Spindle Speed 1800 rpm, feed 0.125 mm and depth of cut 0.15 mm. It was also observed that the range of cutting forces for LN-12 hours of holding time was 17.72 Kgf to 30.38 Kgf, the range of cutting for LN-24 hours holding time was 19.02 Kgf to 30.03 Kgf and the range of cutting force for LN-36 hours holding time was. It was observed that the overall range of tool wear for LN-24 hours holding time is minimal compared to LN-12 and LN-36 hours of holding time.

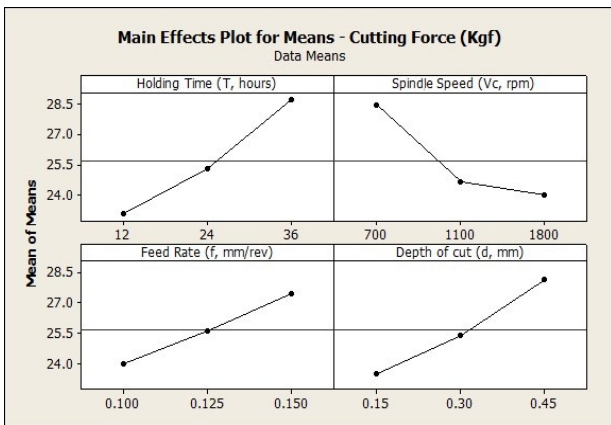
Table 6 depicts the ANOVA results of cutting forces. It was observed that the P-value for holding time (0.002) is minimum followed by Spindle Speed (0.005) and followed by the depth of cut (0.005). This gives a clear understanding that holding time is the most significant factor with percentage contribution (29%) followed by cutting forces the second most significant parameter with percentage contribution of (18.8%) and third most significant parameter depth of cut with percentage contribution of (12.4%). In the case of interactions, none of the interaction has P value less than 0.005

which shows that there is no interaction affecting the cutting force generated during experimentation.

**Table 6: Cutting forces – ANOVA**

Source	DF	Seq SS	Adj SS	Adj MS	F	P	P (%)
T	2	13.0225	13.022	6.5113	22.54	0.002	29.9
Vc	2	8.1909	8.1909	4.0955	14.18	0.005	18.8
F	2	5.1269	5.1269	2.5635	8.87	0.016	11.8
D	4	8.2597	8.2597	4.1299	14.30	0.005	18.9
Vc*F	4	1.3293	1.3293	0.3323	1.15	0.417	3.1
Vc*D	4	0.5191	0.5191	0.1298	0.45	0.771	1.2
F*D	4	5.3673	5.3673	1.3418	4.64	0.048	12.4
Error	6	1.7333	1.7333	0.2889			
Total	26	43.5491					

S = 0.5375 R-Sq = 96.0% R-Sq(adj) = 82.8%



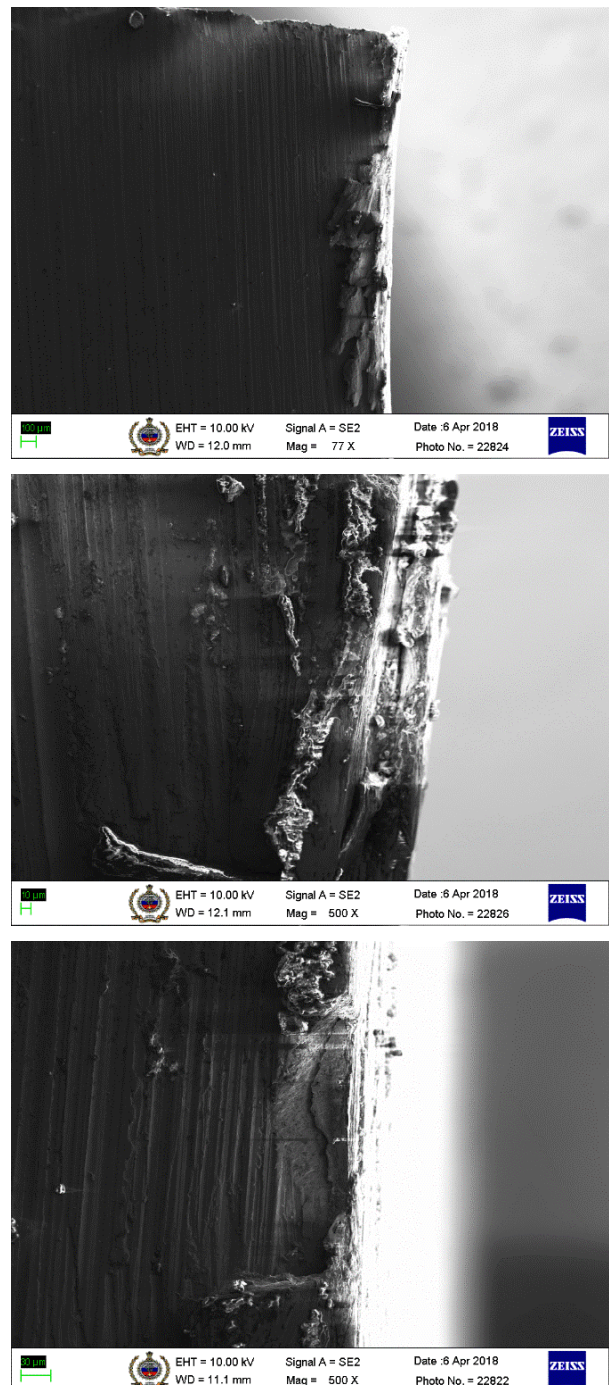
**Figure 6: Main effect plot – Cutting Force**

It can be seen from Figure 6 that within the scope of this investigation the cutting forces recorded during machining are decreasing as the holding time is increasing from LN-12 to LN-24 hours and later by increasing the holding time of the tool wear. So LN-24 hours can be considered as optimum holding time. It is also observed that as Spindle Speed of the cutting tool increases, there is a decrease in the machining force. For variation in cutting tool speed from 700 rpm to 1800 rpm, the average machining force remains the same. With the increase in Spindle Speed, the shear angle increases, resulting in chip thickness size reduction and hence the machining force decreases. So higher Spindle Speed is desired for optimum performance of forces, as feed rate of the cutting tool increases, the contact area of the work part and tool increases, which in turn increases the machining forces. The increase in machining force due to increase in feed rate is evident from the graph. Similar behavior is observed in the case of depth of cut, an increase in depth of cut increases the machining forces. So higher Spindle Speed with a combination of low feed and depth of cut is essential in reducing the forces, which in turn improves the tool life.

#### 4. SEM IMAGES OF TOOL TIP

Figure 7 depicts the SEM images of M2 Liquid Nitrogen treated tool samples. Figure 7 (a, b) shows the SEM images of the tool after cryogenic treatment with LN-12 hours of holding time for machining at the speed of 1800 rpm, 0.1 mm feed and 0.45 mm depth of cut. The images were taken at 250X zoom and 500X zoom. From

the images, it was observed that chipping has taken place at tool edge. Figure 7 (c, d) shows the SEM image of the tool after LN-36 hours of holding time machined with a speed of 1800 rpm 0.15 mm feed and 0.45 mm depth of cut. The images were taken at 250X zoom and 500X zoom. It was observed that the tool surface was worn out due to abrasion and delamination on the edges were observed. The surface wear mainly occurred because of high cutting force generated due to a high depth of cut. Very little material was found deposited on the tool surface. Figure 7 (e, f) shows the SEM images of the tool after LN-24 hours of holding time of cryo-genic treatment machined at speed of 1800 rpm, 0.1 mm feed and 0.3 mm depth of cut. It was observed that tooltip was damaged after machining. From the images of the tooltip abrasion, diffusion and chipping were found on the tooltip resulting in flank and crater were.



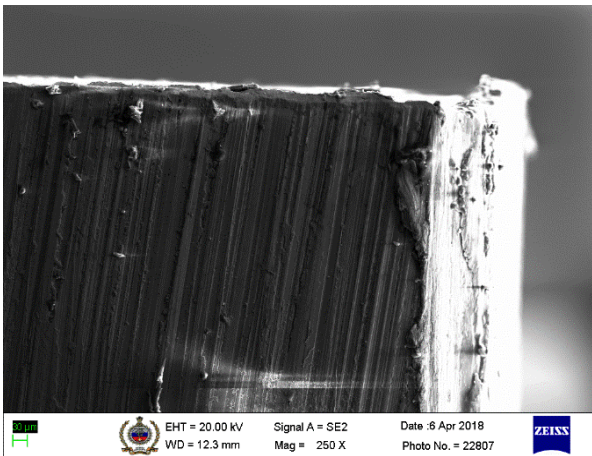
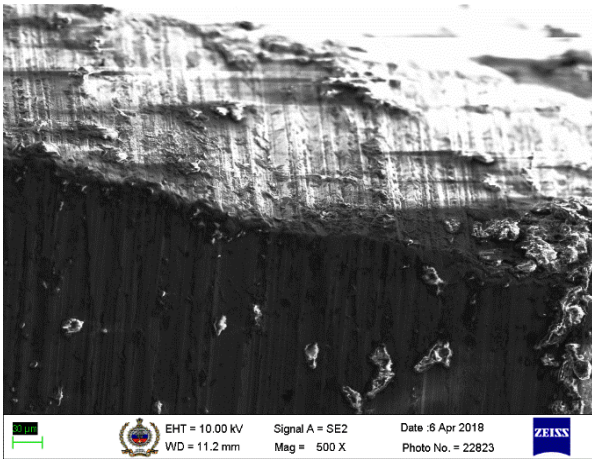


Figure 7: SEM Micrograph images of (a,b) worn surface of LN-12 holding time (c,d) worn surface of LN-36 holding time (e,f) worn surface of LN-24 holding time

## 5. REGRESSION ANALYSIS

Linear regression method was applied to draw out the mathematical relation between output and input parameters. Referring to the results obtained from ANOVA the equations were drawn out for each tool steel material separately. To identify the most significant parameter, the value of ‘ $\alpha$ ’ is compared with the value of ‘P’ and the values of P which were above 0.05 were neglected during the regression equation as the analysis was done for 95% confidence interval.

Equation 4-6 shows the correlation between the output variables with respect to input variables.

$$V_{b\max} = 0.0232 - 0.00106XT + 0.000030XCS + 0.411XF + 0.141XD - 0.000001XCSXD \quad (4)$$

$$Ra = 1.81 - 0.00710XT - 0.000189XCS + 8.41XF + 1.34XD - 0.000296XCSXD \quad (5)$$

$$CF = 19.9 - 0.109XT - 0.00297XCS + 54.4XF + 12.0XD \quad (6)$$

## 6. EXPERIMENTS FOR CONFIRMATION OF RESULT

Confirmatory experiments were performed to validate the model equations 4 – 6. The Experiments were performed by selecting three new sets of random variables which do not belong to the Design of experiments as a part of validation. The parameters used for confirmatory experiments are shown in Table 8. The confirmatory experiment was denoted as C1, C2 and C3 respectively.

Table 8: Selected Cutting parameters for conformation test

Sl.no	T (Hours)	Vc (RPM)	F (mm/rev)	D (mm)
C1	12	800	0.12	0.2
C2	24	1200	0.16	0.4
C3	36	1600	0.18	0.5

Table 9: Result of Confirmation test

Sl.no	Test	Experiment	Model	Error (%)
<b>1 Tool Wear VB max</b>				
C1		0.1173	0.1118	4.95%
C2		0.1619	0.1554	4.23%
C3		0.1866	0.1767	5.62%
<b>2 Surface roughness Ra(μm)</b>				
C1		2.9629	2.8034	5.69%
C2		3.3486	3.1523	6.23%
C3		3.3583	3.1990	4.98%
<b>3 Cutting Forces (Kgf)</b>				
C1		25.4306	25.1440	1.14%
C2		28.0026	27.2240	2.86%
C3		27.7076	27.0160	2.56%

Table 9 displays the outcomes gained by comparing the values acquired from the mathematical model created using the random variable (Eqs. (4) – (6)); with the values obtained from the experiments carried out using the variables from table 5.21. The Error percentage obtained for tool wear VB max (max. value 5.62% and min. 4.23%), Surface roughness Ra (μm) (max. value 6.23% and min. 4.98%) and Cutting Forces (Kgf) (max. value 2.86% and min. 1.14%) for M2 tool steel when compared with predicted values obtained from the model are not exceeding 7 % which is in the accepted limit. Therefore the mathematical models obtained for tool wear, cutting forces and surface roughness are within the degree of approximation.

## 7. CONCLUSION:

The study is aimed at Liquid nitrogen treatment of M2 tool steels and evaluating the effect of different holding durations on the machining performance during turning operations. The study was carried out using M2 single-point cutting tools which were Liquid nitrogen treated for 12 hours, 24 hours, and 36 hours durations at -196°C temperature. The material selected for turning

experiments was low carbon steel with 0.19% carbon content. Tests were conducted as per the order generated by Taguchi's L27 orthogonal array. Three variables, namely Spindle Speed, Feed rate, and Depth of cut, were used with three levels to experimentally analyze the quality of machining and its effect on tool wear. Following conclusions can be made from the results of the study:

The observation of microscopic images after experimentation indicates that the 24 hour Liquid nitrogen treated tool exhibited a minimum tool (flank) wear of 0.055 mm with machining variables set to 700 rpm speed, 0.125 mm/rev feed rate and 0.15 mm depth of cut. The maximum tool wear of 0.209 mm was observed for the specimen with 12 hours LNT with machining parameters set to 700 rpm speed, 0.125 mm/rev feed rate and 0.3 mm depth of cut. From these observations, it can be concluded that the maximum tool (flank) wear was observed for 12 hours LNT and minimum for 24 hours LNT.

The surface roughness of the machined surface was measured considering the Ra parameter, and it can be observed that the value ranges between 2.5  $\mu\text{m}$  and 3.566  $\mu\text{m}$  for all the experiments. And the machined surface is found to be smoother when the machining is carried out with 24 hour Liquid nitrogen treated tool. The ANOVA of the results indicates that the surface roughness is influenced by feed (29.2%) followed by holding time (21.2%), Depth of cut (13.7%) and Spindle Speed (15.3%).

Cutting forces are found to be reducing with 24 hour LNT tools compared to 12 hours and 36 hours LNT tools and for 24 hour LNT tools, the cutting forces were found to range between 22.84 Kgf and 32.40 Kgf. ANOVA results indicate that the holding time is the most significant factor influencing the cutting forces with percentage contribution 29% followed by speed and Depth of cut (18%) and finally feed rate with a percentage contribution of (12.4%).

The SEM analysis of worn surfaces of the tools indicates the chipping phenomenon near the cutting edge, suggesting an impact between the tool and workpiece. The presence of surface wear indicates abrasion and peel off of the tool surface due to higher values of feed rate and Depth of cut during machining. Material deposition from the workpiece to tool surface is found to be minimal for the LNT tools. From the images of the tooltip abrasion, diffusion and chipping were located on the tooltip resulting in flank and crater were.

Linear regression analysis was carried out to build a regression model to predict the tool wear, surface roughness, and coefficient of friction during the machining operations. From the confirmation tests, it is found that the model fits within limits and with a maximum error of around  $\pm 6\%$ .

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**ЕВАЛУАЦИЈА ПЕРФОРМАНСИ ОБРАДЕ М2  
РЕЗНОГ АЛАТА ТРЕТИРАНОГ ТЕЧНИМ  
АЗОТОМ КОД ОБРАДЕ НА СТРУГУ**

**С. Кумар, А. Бонгале, Н. Кедкар**

Рад се бави М2 алатним челиком третираним течним азотом у трајању од 12, 24 и 36 часова на температури од  $-196^{\circ}$  Ц код кога је потом примењено отпуштање на температури од  $150^{\circ}$  Ц. Третирану узорци су коришћени за обраду ниско-угљеничног челика на ЦНЦ стругу при различитим брзинама вретена (700, 110 и 1800 rpm), брзини помоћног кретања (0,1; 0,125 и 0,15 rev/min) и дубини резања (0,15; 0,3 и 0,45 mm). Тагучијев план експеримента и ANOVA су коришћени за статистичку анализу параметара резања и сила резања код хабања алата и хрпавости површине после изведеног експеримента. SEM анализом је испитан тип хабања код резног алата. Регресионом анализом је добијен модел за предикцију вредности хрпавости површине, хабања алата и коефицијента трења са максималном грешком  $\pm 6\%$  на основу реалних експерименталних вредности.