Effect of Cryogenic Treatment on Tool Life of HSS Tool (S400) and Surface Finish of the Material in Turning of SS304

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Abstract. Tool steels are the most widely used components for the single point cutting tool in the turning process. Therefore the characterization of the properties of these tool materials has a great significance when turning is carried out. Alteration and improvement of the properties of these tool steels will enhance the machining process. The present work explores the effect of cryogenic treatment done on a single point cutting tool (HSS) which helps in machining different tool materials with a better surface finish and increased tool life. Turning operation is done on commercial grade material SS304 by using both cryogenically treated and non-treated HSS tool bits at three different speeds (180, 300 & 530 rpm) with the time interval of 3 minutes until the nose fracture is observed. The graphs were plotted between the tool wear and time interval for each speed comparing both the tool lives and it is found that the cryogenically treated tool has sustained for more time than non-cryogenically treated tool at any given speeds standing with more tool life. Also the forces generated during the operation were observed by tool force dynamometer and found to be more in NTT than CTT and even the surface finish of the work piece got enhanced when CT tool is used at any given speeds.

Keywords. Cryogenically Treated, Tool Nose Fracture, Tool Wear and Surface Finish.

1. Introduction

Turning is the basic machining process where the workpiece is rotated while a single point cutting tool moves parallel to the axis of rotation resulting in metal removal. At this instant, at the chip-tool interface where the metal is removed due to friction, large heat is liberated. Due to this the tool wear takes place to a large extent and ultimately the tool fails. This brought about an extensive research in cryogenics. It is defined as the branches of physics and engineering that study very low temperatures, how to produce them, and how materials behave at those temperatures. Cryogenic treatment is a type of heat treatment process applied to materials at low temperatures [13]. During cryogenic treatments, samples are cooled gradually by means of a control unit using liquefied gases such as nitrogen and helium cooled by the system to temperatures varying between -80°C and 196°C[2]. After a waiting period, the samples...
are gradually brought back to the room temperature. Cryogenic treatment is a one-time permanent treatment process and it affects the entire cross-section of the material usually done at the end of conventional heat treatment process but before tempering. Also it is not a substitute process but rather a supplement to conventional heat treatment process. In this regard, out of all the tool materials the High Speed Steel (HSS) has proven to be the most reliable material for cryogenic treatment [12]. Barron et al. [1] have carried out a number of tests on high speed steel tools and have arrived to a conclusion that cryogenic treatment improves wear resistance as well the surface hardness and thermal stability of various materials. D. Candane et al.[3] studied the microstructure and mechanical properties of cryogenically treat tool as said that the cryogenic treatment results in the conversion of austenite to marten site thus increased toughness and hardness, homogeneous carbide distribution and the transformation of retained austenite is observed at low temperatures in tool steels. This treatment is done to make sure there is no retained austenite during quenching. To eliminate retained Austenite, the temperature has to be lowered. The cryogenic treatment is very advantageous as it enhances the metal cutting properties and surface roughness [6]. The cryogenic treatment on improves the tool features such as wear resistance, hardness, toughness and electrical conductivity due to the constriction developed by low temperatures and also due to the homogeneous carbide distribution[11]. The reduction in the flank wear might improve tool life. In the present work the effect of deep cryogenic treatment on HSS tool in turning of SS304 stainless steel has been found out and it influence on the tool life has been seen.

2. Tool and Workpiece

2.1 Selection of tool

The HSS tool samples considered in this work are M2 and S400 steels procured from Miranda (ISO – 9002 company) with dimensions 12.70 x 152.40 mm. Some of the HSS tool bit blanks were made into single point cutting tools for turning with standard tool signature while other tool blanks were sent for deep cryogenic treatment to Cryoking, Surat. The composition of the tool is given in the table 1 below.

| Metals | C | Cr | W | V | Mo |
|--------|---|----|---|---|----|
| % composition | 0.95 | 4 | 6 | 2 | 5 |

2.2 Selection of work piece

The work material used for the purpose of experimentation was taken from the commercial Grade 304 SS with composition as shown in table 2 below.

| Metals | C | Si | Mn | P | S | Cr | Ni |
|--------|---|----|----|---|---|----|----|
| % composition | 0.08 | 0.75 | 2 | 0.045 | 0.03 | 18 | 8.02 |

3. Experimentation

3.1 Cryogenic treatment

The deep cryogenic treatment was carried out as per the following process parameters given in the table 3 as shown below.
Table 3. Cryogenic Parameters

| Parameter            | Value |
|----------------------|-------|
| Soak temperature     | -185°C|
| Soak period          | 24 hours|
| Cooling rate         | 1°C per min |
| Heating rate         | 1°C per min |
| Tempering temperature| 200°C  |
| Tempering period     | 1 hr. |
| Tempering cycle      | 1 |
| Total cycle time     | 34 hrs. |

The above cryogenic treatment cycle can be seen below in figure 1. This shows how the temperature was brought down from room temperature to the cryogenic temperature and maintained. The second part of the picture shows the tempering process which was carried out at 200°C and the same temperature was sustained up to a time period of 1 hour.

3.2 Methodology

Step 1: The workpiece of three different lengths was taken as shown in the table 4 for three different speeds and it was machined for 15 minutes with CT and UT HSS tools with a constant depth of cut and feed.

Step 2: The flank wear, hardness, cutting forces and surface roughness was observed both in case of CT and UT HSS tools for various speeds of the spindle.

Step 3: The machining was carried out till the nose fracture was observed on the tool for the selected speeds using both CT and UT HSS tools.
### Table 4. Lengths of work pieces for selected speeds

| Type of speed | Speeds taken (rpm) | Work piece Length (mm) |
|---------------|-------------------|------------------------|
| Low speeds    | 180               | 127                    |
| Medium speeds | 300               | 145                    |
| High speeds   | 530               | 179.5                  |

### 4. Observations

The below tabulated values were obtained after the experimentation conducted using both CT and NT HSS tools for the selected speeds. Table 5 shows the values for CT tools and table 6 shows the values for NT tools.

### Table 5. Experimental values for cryogenically treated HSS tools.

| S.no | Speed (rpm) | Time (min) | X | y | z | Initial | Final | difference | Hardness | Roughness (μm) |
|------|-------------|------------|---|---|---|---------|-------|------------|----------|----------------|
| 1    | 180         | 1-3        | 10| 13| 16| 2.37    | 2.29  | 0.08       | C46      | 5.029          |
|      |             | 4-6        | 12| 17| 18| 2.29    | 2.35  | 0.02       | C50      | 3.913          |
|      |             | 7-9        | 19| 29| 18| 2.35    | 2.36  | 0.01       | C52      | 5.73           |
|      |             | 10-12      | 14| 15| 23| 2.36    | 2.33  | 0.03       | C60      | 7.05           |
|      |             | 13-15      | 15| 16| 30| 2.33    | 2.36  | 0.03       | C57      | 7.177          |
|      |             | 1-3        | 23| 30| 19| 1.95    | 1.75  | 0.01       | C43      | 2.537          |
|      |             | 4-6        | 28| 42| 27| 1.75    | 1.74  | 0.01       | C33      | 5.822          |
| 2    | 300         | 7-9        | 28| 40| 25| 1.74    | 1.73  | 0.02       | C37      | 4.963          |
|      |             | 10-12      | 29| 44| 28| 1.73    | 1.67  | 0.04       | C29      | 3.744          |
|      |             | 13-15      | 33| 43| 28| 1.67    | 1.57  | 0.05       | C22      | 4.029          |
|      |             | 1-3        | 3 | 18| 12| 2.2     | 2.12  | 0.08       | C34      | 4.836          |
|      |             | 4-6        | 9 | 18| 16| 2.12    | 2.05  | 0.08       | C23      | 5.415          |
|      |             | 7-9        | 13| 29| 25| 2.05    | 1.75  | 0.12       | C46      | 6.023          |
|      |             | 10-12      | 9 | 26| 9  | 1.75    | 1.67  | 0.08       | C28      | 5.728          |
|      |             | 13-15      | 12| 27| 17| 1.67    | 1.6   | 0.07       | C43      | 4.586          |
Table 6. Experimental values for non-treated HSS tools.

| S.NO | Speed (rpm) | Time (min) | Cutting Forces (Kgf) | Flank Wear (mm) | Hardness | Roughness |
|------|-------------|------------|----------------------|-----------------|----------|-----------|
|      |             | X          | Y                    | Z               | Initial  | Final     | Difference | Number | (μm) |
| 1    | 180         | 7-9        | 12                   | 26              | 8        | 3.5 3.16  | 0.07       | C33    | 1.558 |
|      |             |            |                      |                 |          | 2.8 2.6   | 0.2        | C40    | 3.302 |
|      |             |            |                      |                 |          | 2.6 2.7   | 0.04       | C20    | 3.522 |
| 2    | 300         | 7-9        | 7                    | 16              | 21       | 2.7 2.67  | 0.03       | C34    | 3.35  |
|      |             |            |                      |                 |          | 2.67 2.74 | 0.08       | C33    | 6.596 |
|      |             |            |                      |                 |          | 2.74 2.7  | 0.04       | C39    | 4.657 |
|      |             |            |                      |                 |          | 2.5 2.26  | 0.24       | C35    | 4.258 |
| 3    | 530         | 7-9        | 22                   | 44              | 39       | 1.8 1.92  | 0.3        | C35    | 5.316 |
|      |             |            |                      |                 |          | 2.7 2.67  | 0.03       | C34    | 3.35  |
|      |             |            |                      |                 |          | 2.67 2.74 | 0.08       | C33    | 6.596 |
|      |             |            |                      |                 |          | 2.74 2.7  | 0.04       | C39    | 4.657 |
|      |             |            |                      |                 |          | 2.5 2.26  | 0.24       | C35    | 4.258 |

5. Calculations
From the cutting forces observed in the experimentation, the total power consumed was calculated and the values of the power consumed has been tabulated which is shown in the table 7 below. It shows a comparison between in the powers in both the CT and NT HSS Tools.

Table 7. Comparison table for power consumed in CT and NT tools

| S.No | Speed (RPM) | Time (min) | Cutting velocity | Cutting forces (N) | Power (W) | Total power (W) |
|------|-------------|------------|------------------|--------------------|-----------|----------------|
|      |             |            |                  | CT               | NT       | CT | NT |
| 3    | 180 RPM     | 9          | 0.01413          | 284.49            | 255.06   | 0.3918 | 0.874 |
|      |             | 12         |                  | 284.49            | 255.06   | 0.3918 | 0.874 |
|      |             | 15         |                  | 156.96            | 264.87   | 0.482  | 0.813 |
|      |             | 3          |                  | 294.3             | 176.58   | 0.902  | 1.5 |
|      |             | 6          |                  | 412.02            | 215.82   | 1.102  | 2.105 |
| 5    | 300 RPM     | 9          | 0.0235           | 392.4             | 156.96   | 0.802  | 2.005 |
|      |             | 12         |                  | 392.4             | 156.96   | 0.802  | 2.005 |
|      |             | 15         |                  | 421.83            | 176.58   | 0.902  | 2.155 |
|      |             | 3          |                  | 176.58            | 284.49   | 1.598  | 2.574 |
|      |             | 6          |                  | 176.58            | 284.49   | 1.598  | 2.574 |
| 5    | 530 RPM     | 9          | 0.04162          | 284.49            | 431.64   | 2.574  | 3.906 |
|      |             | 12         |                  | 284.49            | 431.64   | 2.574  | 3.906 |
|      |             | 15         |                  | 255.06            | 588.6    | 2.308  | 5.327 |
|      |             | 15         |                  | 264.87            | 627.84   | 2.397  | 5.682 |
6. Inferences and Results

6.1 Cutting Force Vs Time

**Figure 2.** Cutting forces vs time for 180 rpm speed

**Figure 3.** Cutting forces vs time for 300 rpm speed

**Figure 4.** Cutting forces vs time for 530 rpm speed
6.2 Cutting Forces Vs Speed

The above graphs in fig 2, 3, and 4 have been plotted for the cutting forces obtained against the time for all the three speeds and in fig 5 cutting forces vs speed has been plotted. It is clearly visible that the cutting forces are always lower in case of cryogenically treated tool at any given time or speed. This is due to lesser wear and distortion being observed at the cutting edge which interacts with the workpiece.[9] Also the decreasing trend of cutting force is observed at 300rpm in cryogenically treated tool, may be because of BUE formation which decreases the tool wear, which in turn decreases the forces. To the knowledge of the author, at lower speeds of 180 rpm, the cutting forces are high due to high frictional forces at the interface of tool and work piece. At higher speeds (530 rpm), high cutting forces are induced in the tool as the BUE generated are flushed off at the time of chip formation resulting in the greater interaction with the workpiece.

6.3 Surface Roughness Vs Speed

The plot in fig 6 is the total surface roughness vs speed and the graph clearly indicates increase in the surface roughness with increasing speed. The surface roughness is less in case of CT tool than NCT tool at any given speed. This may be due to the finer grain size in the cryogenically treated tool a microstructural level [9] resulting in lesser surface imperfections thereby improving the surface finish. Soma Kumar et.al [10] stated that at low cutting forces, lesser vibrations in machines are induced. There by improving the surface finish.
6.4 Power Vs Speed

The graph in fig 7 shows the variation of power with speed and the power consumed increases with the increasing speed. The power consumed in case of CT tool is less as compared to the non-treated tool. This may be due to improved grain structure in the cryogenically treated tool which lowers the friction at the interface. This reduces the cutting forces and hence the power consumed is reduced in the entire operation.

6.5 Hardness Vs Speed

The influence of cryogenic treatment on hardness of the workpiece is very minimal. In the comparison to the non-treated tool and cryogenically treated tool the hardness at any given speed is lower may be because CT tool reduces the surface micro cracks and imperfections at the dynamic loading. Due to this the residual stresses will be lowered improving the fatigue strength and hardness [11]. This can be observed in fig 8 in the hardness vs speed graph.
6.6 Flank Wear Vs Time till Nose Fracture

**Figure 9.** Tool life Comparison for both CT and NCT until nose fracture is observed in 180 rpm.

**Figure 10.** Tool life Comparison for both CT and NCT until nose fracture is observed in 300 rpm.

**Figure 11.** Tool life Comparison for both CT and NCT until nose fracture is observed in 530 rpm.
6.7 Tool Life Vs Speed

The flank wear is always on the increasing side with increasing time and it is on the lower side in case of cryogenically treated tool. The flank wear also increases with increasing speed in both the tools. This is observed in fig 9, 10 and 11 plotted above versus time. The tool was worn out till the nose fracture was observed. The times were noted at the time of nose fracture was observed in the tool and the corresponding time may be considered as the tool life. The above plot in fig 12 shows the tool life w.r.t speeds and it can be seen that the tool life decreases with increasing speed but it is higher in case of cryogenically treated tool as compared to non-treated tool. Due to cryogenic treatment, there is a reduced abrasion in the tool which reduces the friction and there is larger heat dissipation because of the increased thermal conductivity [9] in the tool. This reduces the flank wear and improves tool life. Barron et al [1] stated that due to cryogenic treatment the microstructure of metal retains austenite at room temperature due to which the wear resistance is substantially improved. The carbide population increases and is distributed evenly throughout in the metal due to cryogenic treatment which improves wear properties.

7. Conclusions

The turning operation is done on SS304 steel using HSS Cryogenically treated (CT) and untreated tool (NCT) at three different speeds of 180, 300 and 530 rpm until the nose fracture of the tool is observed, keeping feed, 0.05mm/rev and depth of cut, 0.5mm constant. The primary response of interest is the tool life which got improved up to 25% at 180rpm, 14% at 300rpm and 20% at 530rpm in cryogenically treated tool compared to untreated tool. This increase in tool life in CT tool is more at low speeds and also more compared to untreated tool at any given speeds, this may be because of the reduction of friction between the tool and work piece interface which in turn reduces the tendency of tool adhesion to the work piece lowering the temperature generated. As the temperature and friction at the working zone is reduced, the tool forces and tool wear are also lower in CT tool than NCT tool. This helps in reduction of the power consumed to finish the operation. Also because of the finer grain structure in the CT tool, it reduces the surface imperfections and the residual stresses developed inside the work piece material, increasing the Surface roughness and hardness compared that generated in NCT tool. Finally it can be concluded that the tool life got enhanced significantly using CT tool than NCT tool for the above particular operation.
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