Experimental investigation into effect of cutting parameters on surface integrity of hardened tool steel

K Bashir*,1, A U Alkali1, M H S Elmunafi2 and N M Yusof2

1 Department of Mechanical Engineering, Kano State Polytechnic, Nigeria
2 Faculty of Mechanical Engineering, Universiti Teknologi Malaysia

*Email: kbmaisallah405@gmail.com

Abstract. Recent trend in turning hardened materials have gained popularity because of its immense machinability benefits. However, several machining processes like thermal assisted machining and cryogenic machining have reveal superior machinability benefits over conventional dry turning of hardened materials. Various engineering materials have been studied. However, investigations on AISI O1 tool steel have not been widely reported. In this paper, surface finish and surface integrity dominant when hard turning AISI O1 tool steel is analysed. The study is focused on the performance of wiper coated ceramic tool with respect to surface roughness and surface integrity of hardened tool steel. Hard turned tool steel was machined at varying cutting speed of 100, 155 and 210 m/min and feed rate of 0.05, 0.125 and 0.20mm/rev. The depth of cut of 0.2mm was maintained constant throughout the machining trials. Machining was conducted using dry turning on 200E-axis CNC lathe. The experimental study revealed that the surface finish is relatively superior at higher cutting speed of 210m/min. The surface finish increases when cutting speed increases whereas surface finish is generally better at lower feed rate of 0.05mm/rev. The experimental study conducted have revealed that phenomena such as work piece vibration due to poor or improper mounting on the spindle also contributed to higher surface roughness value of 0.66Ra during turning at 0.2mm/rev. Traces of white layer was observed when viewed with optical microscope which shows evidence of cutting effects on the turned work material at feed rate of 0.2 rev/min

1. Introduction

Tool steels are one of the major consumed materials for engineering products because of their good thermo-mechanical properties. Tool steels presents various machining challenges like frequent tool failure, poor surface finish and surface integrity. It is also classified among the difficult-to-cut material because of their inherent hardened characteristics. Tool steels presents poor machinability factors like high surface roughness which impacts negative effects on the component that is produced like decreased fatigue life and corrosion resistance and high coefficient of friction. Fewer literatures have been published so far on the investigations on surface finish of tool steel during cutting with wiper coated ceramic insert. Alkali et al [1] have investigated the influence of cutting parameters on chip morphology using dry turning of AISI O1 tool steel. Their investigation does not report the influence of the mentioned parameters on surface finish of the AISI O1 tool steel. Yağıcı [2] conducted an investigation on hardened tool steel (HRC 52) during hard turning with mixed ceramic cutter. Their investigation revealed that surface roughness values that were obtained while cutting with ceramic tools were found higher than those obtained with cubic boron nitride (CBN) tool. The study further reported that the cutting force components obtained while cutting with CBN tool were found higher...
than those obtained with mixed ceramic tool. However, Christina [3] reported that the major factor responsible for machinability influence have been the cutting parameters like cutting speed, feed rates, cutting tool geometry, edge preparation and type of work material among others. Thus, the impetus of the current investigation is to study the influence of wiper coated ceramic cutting tool on surface finish and surface integrity of AISI O1 tool steel. Sudhansu et al [4] investigated the resulting surface roughness of AISI 52100 steel during finish turning with CBN tool. Their investigation revealed that feed rate was found to be the only significant factor on arithmetic average (Ra) surface roughness with percent contribution of 68.12%, followed by cutting speed which contributed 25.11%. Samardžiová et al [5] studied the surface roughness parameters Ra and Rz of hardened steel (100Cr6) using mixed ceramic insert. Their investigation revealed that it is possible to achieved more than two times lower values of surface roughness parameters Ra and Rz with wiper geometry cutting tool than conventional geometry cutters when they are use at the same cutting parameters. Their investigation further concluded that insert geometry influences surface quality, especially surface roughness parameters. The study further reported that it is possible to use wiper geometry (which is different from the conventional geometry in the shape of the minor cutting edge), when better surface quality is needed. This study will report the performance of wiper coated ceramic tool on surface integrity and surface finish of AISI O1 tool steel.

1.1. Wiper geometry turning insert

Another overwhelming drive for adopting the wiper geometry insert during this investigation is its ability to increase feed rate twice while keeping abreast the surface finish. Hence, cutting with wiper geometry is often regarded as high feed rate hard turning [6]. Another advantage attributed with high–feed cutting inserts like wiper geometry is their ability to maintain a low surface roughness of the machined surface and obtained super finished surfaces. An evident outcome of such inserts is improved productivity by increasing efficiency and lowering production costs [6, 7]. This investigation used rhomboid wiper geometry ceramic insert ANSI coded CNGA 120412EFW. The ceramic tool was mounted on left corner tool holder and that was geometrically coded Kennametal MCLNL 16161412.

2. Experimental Set up

2.1. Work piece material

Through hardened cylindrical tool steel bar obtained from AISI O1 was used as work piece material. Tool steel is a general purpose oil hardened tool steel suitable for a wide variety of cold-work applications. The steel was selected for this study because of its inherent machinability characteristics, good dimensional stability in hardened state, good combination of high surface hardness and toughness after hardening and tempering. The hardness of the material is 55HRC.

2.2. Cutting Tool Material

As reported in section 1.1, the rhomboid shaped coated wiper ceramic tool ANSI coded CNGA 120412EFW has a tool nose radius (rε) of 1.2 mm. The geometrically coded Kennametal MCLNL 16161412 ceramic tool was mounted on left corner tool holder and has the following geometry:

- Side rake angle $\gamma = -5^\circ$
- Back rake angle $\alpha = -5^\circ$
- Side cutting edge (SCEA) = $-5^\circ$
- Nose radius $r = 1.2$ mm
3. **Experimental set-up**

To obtain a proper shaped facial area, the work piece was machined on the faces and center drilled at both ends to enable support between centers both in order to minimize vibration as well as impact of forces that may result from shearing. Cutting tool was mounted and securely held in position and aligned with the work piece at both X and Z coordinates being references for the machine set up. To facilitate tool entry, a chamfer was made at the end of the work piece. The surface roughness (Ra) of machined part was measured using a Portable surface profilometer (Brand/Model: Taylor Hobson Surtronic 3+) three times per cut. A cut-off length of 0.8 mm was used to compensate for surface waviness while an average of these reading was taken. Thereafter overall average was eventually recorded for each experimental.

4. **Result and discussions**

4.1. **Effect of Cutting Speed on the Surface Roughness**

It was observed that the surface roughness improves as the cutting speed increases from 100m/min to 210m/min. At high cutting speed, the frictional force decreases due to the increase of temperature. Hence, this improves the surface finish. However, it is observed that at higher cutting speed, the surface finish was better. This is shown in Figure 1 which shows the surface roughness when the cutting speed is increased to 200m/min.

![Figure 1. Surface Roughness of AISI O1 Tool Steel at Various Cutting Speed](image)

4.2. **Effect of Feed Rate on the Surface Roughness**

The increase of feed rate results in an increase of the surface roughness values Ra, where the surface roughness at 210m/min with a feed rate of 0.05mm/rev appears to have a better Ra value compared to when feed rate is at higher value. This is to say, that surface finish is generally better at lower feed rate of 0.05mm/rev, whereas the poor surface roughness was recorded at 100m/min with a feed rate of 0.2mm/rev, as shown in Figure 2.
4.3. **Surface Roughness Propagation**

Surface roughness propagation is effected by many conditions. The experimental study conducted revealed that phenomena such as work piece poor or improper mounting on the headstock spindle or mismatched in support of the work piece from the tail stock centre could result in higher surface roughness value. This in turn, affects the cutting tool, causing it to wear rapidly. Additionally, it is observed that the abrasive action of the deformed chip with the machined surface influences the surface roughness. It is also observed that the chips formed under the conditions investigated, were continuous chips which later curled and surrounded both the machined surface of the work material and of course the cutting tool rake face, hence contributing to crater wear on the cutting tool. At a feed rate of 0.05mm/rev, the surface roughness was found to be fair with the three sets of cutting speed investigated in this study. However, at 0.2mm/rev the roughness value was higher up to an average of 0.67μm with a corresponding cutting speed of 100m/min. This summarized the fact that, at lower feed rates the surface roughness always has a lower value which manifests in the form of good surface finish. These values gradually become better with increasing cutting speed. Figure 3 shows the surface roughness propagation.

![Surface roughness vs feed rate](image1.png)

**Figure 2.** Surface Roughness of AISI O1 Tool Steel at Various Feed Rate.

![Surface roughness propagation](image2.png)

**Figure 3.** Surface Roughness Propagation when Turning AISI O1 Tool Steel
Although surface roughness value is imminent during the metal cutting, this study observed that, at every first cut in each experiment, the surface roughness value was found higher than the second cut. This is assumed to be due to the sharp cutting tool tip which becomes rounded after the first cut and before it is affected by a wear. The micro indentation obtained was in the range of 52 – 55 HRC. The micro indentation readings obtained were basically higher than those obtained on the machined work piece material. Guo and Sahni [8] also reported in his study that the change in hardness of a turned part was caused by the extremely small grain size and high dislocation density.

It is further observed that white layer exists with two layers. A dark layer beneath the white layer but above the bulk material as well as the white layer on top of the dark layer. The White layer appears white under an optical microscope after polishing and etching as evident and appeared smoother than bulk material as captured with SEM shown in Figure 5.

5. Conclusion

Based on the results and analysis carried out in this study during dry turning AISI tool steel with hardness 55 HRC using wiper edge preparation coated ceramic cutting tool, the study have revealed that the surface roughness improves as cutting speed increases from 100m/min to 210m/min. Surface finish is generally better at lower feed rate of 0.05mm/rev, whereas the poor value of surface roughness was recorded at 100m/min with a feed rate of 0.2mm/rev. Based on the presented result of the investigation obtained, it is recommended that the effect of cutting edge preparation and tool wear on the residual stresses should be investigated.
References

[1] Alkali A U, Noordin M Y, Elmunafi M S H, and Fawad H, 2013 Int. J. of Mater, Mech. Manuf, 1, 1

[2] Yalçın B, 2015 J. of the Trans. of the Can. Soc. Mech. Eng., 39, No. 2.

[3] Cristina B, 2015 Int. J. Sci & Eng Res, 6 5 2229-5518

[4] Sudhansu R D, Debabrata D and Amarendra K, 2014 Proceed. of Res., 5th Int. & 26th All India Manu. Tech., Design and Res. Conf.

[5] Samardžiová M, & Neslušan M, 2013 Facul. of Mater. Sci. and Tech. in Trnava Slovak Uni. of Tech.

[6] Ozel T, Karpat Y, Figueira L and Davim P, 2007 J. Mater. Process. Tech. 189 192–198.

[7] Stachurski W, Kruszynski B and Midera S L 2012 Mechanics and Mech. Eng’rng 16. 1 25–32

[8] GuoY B and Sahni J 2004 Int. J. Mach Tool Manu. 135 – 145