Surface roughness analyses on hard martensitic stainless steel by turning

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1. Introduction

The challenge of modern machining industries is mainly focused on the achievement of high quality, in terms of work piece dimensional accuracy, surface roughness, high production rate, less tool wear on the cutting tools, economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact. In most practical applications of engineering components, materials suffer from deterioration by mechanical and / or chemical effects present in their operating environments [1]. The martensitic stainless steel will have poor corrosion resistance because of limitations in chromium and nickel content [2]. One study suggests that hard dry turning requires high performance cutting tools and extremely rigid machine tools. Matsumoto et al [3] turned several AISI E 52100 hard steels work pieces using ceramic and PCBN tools in a lathe of conventional design with 60 HRC. The performance of ceramic and CBN cutting tools and the quality of the surfaces machined are highly dependent on the cutting conditions. i.e. Cutting speed, feed rate, depth of cut and the tool nose radius which significantly influence surface roughness, white layer formation and tool wear[4-5].

ABSTRACT

Purpose: The purpose of this research paper was to analyze the surface roughness produced by turning process on hard martensitic stainless steel by Cubic Boron Nitride cutting tool. The work piece material was hard AISI 440C martensitic stainless steel.

Design/methodology/approach: The experiments were designed using various operating parameters like cutting speed, feed rate and depth of cut. These operating parameters are predominantly used in carrying out the experiments.

Findings: Low surface roughness was produced at cutting speed of 225 m/min with feed rate of 0.125 mm/rev and 0.50 mm depth of cut (doc). However, moderate cutting speed of 175 m/min under above feed rate and doc is an ideal operating parameters taking flank wear in to account.

Research limitations/implications: While searching for references in turning of martensitic stainless steel, very limited journals are available, but very few literatures are available on turning of AISI 440C hard martensitic stainless steel which was a constraint.

Practical implications: The turning of hard martensitic stainless steel brings interesting information on surface roughness, tool wear etc. and further can be extended to turn with different cutting tools.

Originality/value: The value of the research work lies in using the results by other researches. The result will upgrade the knowledge about the influence parameters on surface roughness especially on martensitic stainless steels.

Keywords: Tool materials; Machining; Surface roughness
view of authors, there are limited literatures available on turning of AISI 440 C material.

2. Experimental procedure

Investigation of turning CBN tool in the machining of hard AISI 440C material was carried out by turning process. The turning experiments were performed using N.C.Harrison 400 lathe. All experiment data were obtained on AISI 440 C hardened steel having hardness between 45 to 55 HRC. The surface roughness was measured using Mitutoyo SJ 400 make. The work piece material was received as 1000 mm length bar having 50 mm diameter. This was cut to 350 mm length, centered on both sides and skin turned to remove oxide formation. The hardening process was done by induction hardening at out side source. The turning was carried out for 150 mm length and it is termed as trial 1,2,3,4, and 5 for each 150 mm length respectively. i.e each cutting edge was repeated every 150 mm length. The flank wear was main wear observed during the experiments, however it was not considered for this presentation.

Table 1. Chemical Composition of AISI 440 C steel

<table>
<thead>
<tr>
<th>Material</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Mo</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISI 440C</td>
<td>0.95-1.20</td>
<td>1.0</td>
<td>1.0</td>
<td>16-18</td>
<td>0.75 max.</td>
<td>0.04</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Table 2. Mechanical properties

<table>
<thead>
<tr>
<th>Material</th>
<th>Tensile Strength (MPa)</th>
<th>Yield Strength (MPa)</th>
<th>% of Elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISI 440C</td>
<td>1965</td>
<td>1900</td>
<td>2</td>
</tr>
</tbody>
</table>

2.1. AISI 440 C Martensitic stainless steel

Among the martensitic stainless steels, AISI 440C has good mechanical properties; it contains high chromium content and high carbon content. The corrosion resistance of AISI 440 C is the lowest among the stainless steel groups because of its high carbon content, which results in the precipitation of carbides phases, although its chromium content is close to that of AISI 304 stainless steel. The practical application of engineering components, materials suffer from deterioration by mechanical and / or chemical effects present in their operating environments. Martensitic Stainless steels are widely used in engineering applications such as steam and water valves, pumps, turbines, compressor components, shafting, cutlery, surgical tools, bearings aero space applications and plastic moulds etc. AISI 440 C has good mechanical properties. The Tables 1 and 2 show the chemical composition and mechanical properties of AISI 440 C steel respectively.

2.2. Cutting tool material

The CBN tool material is one of the hardest known after diamond. It is a super abrasive material and has a cubic atomic structure, like diamond. Its main characteristics are its grain size, its percentage of CBN and its types of binder. During the turning, the cutting edge experiences high cutting temperature and cutting forces. The CBN tools NP-TNGA160412G3 MB8025 and the holder MTINR2020KL16N was used in the present work and commercially available grades manufactured by Mitsubishi. The nose radius of the cutting edge was 0.40 mm. There were three cutting tools which contain three cutting edges and totally 9 cutting edges available for turning. The turning was carried for 150 mm length and totally 750 mm length turned for each cutting edge. At the end of each trail, the surface roughness was measured.

3. Results and discussion

3.1. Surface roughness

Surface properties such as roughness is critical to the function-ability of machined components and this is increasing component functionality [6-7]. Many researchers have conducted experiments to determine the effect of parameters such as cutting speed, feed rate, nose radius and depth of cut as the principal parameters on surface roughness and tool wear in hard turning [8-9]. CBN turning tools have lower toughness than other common tool materials is more likely [10]. Chou et al [11] experimentally investigated the influence of CBN content on surface quality and tool wear in turning hardened AISI 52100 steel tool. This study included that low content CBN tools produce better surface roughness with respect to higher content CBN tools and depth of cut has minor effect on tool wear rate [11]. As tool flank wear increases surface roughness also increases [12]. The various simple surface roughness parameters used in the industries such as average roughness (Ra), root mean square RMS and maximum peak to valley [7, 13].

The theoretical arithmetic average surface (mm)

\[
Ra = 0.032 f^2 / R
\]  

where \( f = \) feed rate (mm/rev) and \( R= \) tool nose radius (mm). It means that surface roughness increases with increasing feed rate and a large tool nose radius reduce surface roughness of the work piece. Harris et al [14] showed that depending on the composition, the hardness of CBN insert changes with temperature. The formation of built up edge will cause tool wear and surface integrity of the work piece [15].

Feed rate of 0.08 and doc of 0.50

The figure 1 shows cutting speed Vs surface roughness having cutting speeds 125, 175 and 225. At low cutting speed of 125, the surface roughness obtained was 27 micron and each 150 mm turning, the surface roughness value was 26, 26, 24 and 54 microns respectively. For 750 mm turning, for the same operating parameters, the highest value was 54 micron. In the same way for the other cutting speeds 175 and 225 m/min, the surface roughness was 28 and 23 micron for 150 mm turning. The cutting speed 225 m/min produced surface roughness of 23 micron. The tool flank wear was not much developed up to 600 mm turning.
Feed rate of 0.10 and doc of 0.75

The figure 2 is the graphical representation of results obtained for operating parameters for 125, 175 and 225 cutting speeds. At these operating parameters, the surface roughness value was 31 micron and high value was 55 micron for turning on both 125 m/min and 225 cutting speed. For the rest of the tests, all the tests readings fell within this range of 26 and 55 microns. When turning at cutting speed of 125, the surface roughness observed was 35 micron and for each 150 mm turning the surface roughness produced was 32, 41, 26 and 57 microns. As the turning continued the surface roughness increased except at 600 mm length, the surface roughness at 175 cutting speed was 39 micron and for each 150 mm turning, the surface roughness observed as 32, 39, 29 and 38 microns respectively. At 225 cutting speed roughness value 46 micron initially but this value fluctuated for 300, 450, 600 and 750 mm. The respective values are 32, 40, 55 and 49 respectively.

Feed rate of 0.125 and doc of 1.00

The feed rate 0.125 with doc of 1.00 would remove more material than the other operating parameters. When comparing the surface roughness produced at start of the experiment at cutting speed of 125 m/min, low surface roughness produced was 31 microns where as at cutting speed of 225 m/min, the surface roughness was 34 microns. There was no much difference between surface roughnesses produced. The surface roughness produced at 175 cutting speed was 24 micron which is slightly lower than 34 microns. As the turning continues for 300, 450, 600 and 750 mm length, the roughness was 41,41.71 and 69 respectively obtained at the end of the experiments. It is shown in the figure 3. The figures 4, 5 and 6 show surface roughness Vs number of trials. The figure 7 shows the formation of flank wear at 175 cutting speed with feed rate of 0.125 and depth of cut of 1.00 mm and grooves and ridges formed. Maximum flank wear occurred was 274 microns at the end of experiment.

Fig. 1. Cutting speed Vs Surface roughness –feed rate of 0.08 and doc of 0.50 mm

Fig. 2. Cutting Speed Vs Surface roughness –feed rate of 0.10 and doc of 0.75 mm

Fig. 3. Cutting Speed Vs Surface roughness –feed rate of 0.125 and doc of 1.00 mm

Fig. 4. No. of trails Vs Surface roughness –feed rate of 0.08 and doc of 0.50 mm

Fig. 5. No. of trails Vs Surface roughness –feed rate of 0.10 and doc of 0.75 mm

Fig. 6. No.of trails Vs Surface roughness –feed rate of 0.125 and doc of 1.00 mm
4. Conclusions

The followings conclusions were drawn based on experiments conducted on hard AISI 440 C stainless steel.

1. It was difficult to predict the performance of the martensitic stainless steel due its characteristics.
2. The surface roughness was 23 micron at high cutting speed of 225 m/min with feed rate of 0.125 and 0.50 mm doc. This may be ideal cutting speed to operate.
3. However, operating at 175 cutting speed with 0.125 feed rate and doc of 1.00 mm may be more suitable taking the flank wear in to consideration.
4. It is always advisable to turn the hard martensitic stainless steel at medium level cutting speed, high feed rate and high depth of cut. Turning at this parameter would also produce generation of heat and intensity may not be high which in turn affect flank wear.

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References