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Tool flank wear analyses on martensitic stainless steel by turning

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ABSTRACT

Purpose: Purpose of this research was to demonstrate tool wear by hard turning of martensitic stainless steel and this material is pronounced as difficult to machine material. The evaluation was done using CBN cutting tool on SS 440 C stainless steel with hardness between 45 to 55 HRC.

Design/methodology/approach: Turning parameters like cutting speed, feed rate and depth of cut was used. The turning was carried out dry process.

Findings: The flank wear was caused by abrasive action between cutting tool and work piece. The heat generated between work piece and tool tip help to form built up edge. The generated heat was conducted easily due to low thermal conductivity of the work piece material. At low cutting speed of 125 m / min with high feed rate of 0.125 mm / rev and 1.00 mm DOC.

Research limitations/implications: It was difficult to decide the operating parameters due to physical and chemical properties of the material. Operating at high cutting speed would result in tool flank wear, surface damage and other wears.

Originality/value: The originality of this paper lies with conducting experiment and finding optimum operating parameters. The other researches can have as reference.

Keywords: Machining; Wear resistance; Flank wear; Technology devices and equipment

PROPERTIES

1. Introduction

Hard turning/ machining is fast developing process and this is being carried out to get net shaped products. This hard machining is reducing the cost of manufacturing and also improves machine utilization, effective use of operator's skill. During turning one of the most important factors is tool wear whether it is soft or hard work pieces. The tools wear are classified as flank wear, crater wear, and nose wear etc. The primary tool wear are classifed as flank wear, crater wear and nose wear, are important wear which will affect the smoothness of the product, cost of operation and performance. During turning tool wear is caused by the normal load generated by interaction between tool work piece and tip [1]. Tool wear which results in tool substitution, is one of the most important economical penalties, so it is very important to minimize tool wear, and optimizing all the cutting parameters like depth of cut, cutting velocity, feed rate, cutting fluids and cutting fluid application [2]. The study of the wear behaviour and predicting tool life of CBN during machining hard martensitic stainless steel is needed. The hard stainless steel like SS 410, SS 420 and SS 440 C is difficult to machine grades due to the high presence of carbon and nickel content. The poor machinability of the stainless steel is usually accounted for reasons having very low heat conductivity, high ductility, high tensile strength, high fracture toughness and work hardening rate. Work hardening of stainless steel is caused after a previous severe cutting operation by a worn tool [3]. Work hardening will cause increased rates of tool wear and damage [4]. It was reported that CBN tool wear becomes more severe in the machining soft steel than machining of hardened steel [5]. Suh [6] suggested that CBN wear is due to chemical instability of the tool material and does not depend on the hardness of the tool once the hardness of the tool is 4.5 times greater than the work piece hardness. Flank wear and end clearance wear probably occur by both abrasive and adhesive wear mechanisms with abrasive wear being the major source of material removal since the temperatures at tool flank lower than that on the rake face. Abrasive is mainly caused by the hard, martensitic structure of the hard work material. The relative motion between the newly cut surface and the flank of the cutting tool in the presence of hard particles results in the development a flat of the flank faces of the cutting tool. Tool material is removed by ploughing, scoring, micro-cutting or grooving) with the said hard particles [6]. A rubbing action takes place between tool flank and hard martensite structure which removes material in the flank side. As the cutting speed and feed rate increase, the temperature in the chip formation region also tends to rise [7].

2. Experimental procedure

Investigation of turning CBN tool in the machining of hard AISI 440 C 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 tool flank wear was measured by Scanning Electron Microscope (SEM) Joel 6380 LA 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 for 150 mm length continuously for 150, 300 , 450, 600 and 750 mm length. i.e. each cutting edge repeated for 5 times. The surface roughness was not considered for this presentation. There were three cutting tools which contain three cutting edges and totally 9 cutting edges available for turning.

2.1. AISI 440 C martensitic stainless steel

Among the martensitic stainless steels, AISI 440 C has good mechanical properties. It contains high chromium and high carbon 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.

Table 1.
Chemical composition of AISI 440 C steel

Material	C	Mn	Si	Cr	Mo	P	S
AISI 440 C	0.95-1.20	1.00	1.00	16-18	0.75 max.	0.040	0.030

Table 2.
Mechanical properties

Material	Tensile Strength (MPa)	Yield Strength (MPa)	% of Elongation
AISI 440 C	1965	1900	2

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 MTJNR2020KL16N was used in the present work and commercially available grades manufactured by Mitsubishi. The nose radius of the cutting edge was 0.40 mm.

3. Results and discussions

3.1. Flank wear

Y. Huang et al [8] observed that wear pattern depend on the CBN tools used, work piece material composition, and cutting conditions. They also concluded that generally, adhesion, abrasion and diffusion are considered to be main tool wear mechanisms in CBN hard turning: however, the individual effect of each mechanism depends on the combinations of the CBN tool and work materials, cutting conditions, tool geometry etc. A few basic mechanisms dominate cutting tool wear are: 1. Diffusion wear affected by chemical loading on the tool and cutting material 2. Oxidation wear - causes gaps to occur in coated film and results in a loss of the coating at elevated temperature, 3. Fatigue wear - is a thermo-mechanical effect and leads to the break down of the edges of the cutting tool, 4. Adhesive wear occurs at low machining temperatures on the chip face of the tool and leads to the formation of a built up edge, and the continual break down of the built up edge and the tool edge itself, 5. Abrasive wear affected by hardness of the work material and is controlled by content of the cutting material [9]. It was found that the temperature rise during cutting could significantly reduce the strength of the tool and hence the wear resistance of the tool [10-11]. The heat generated during machining could reduce the strength of the work piece [12]. Abrasive wear is the damage to the surface, which arises because of the relative motion to that surface of either harder asperities or perhaps hard particles trapped at the interface. The high temperature generated during machining of stainless steel has been the primary concern because it can reduce the tool life, and affect the surface and sub surface of the machined work piece [13]. The hard abrasive foreign particles in the work material can play a significant role in the wear of tools in which under conditions of sliding. In machining steel alloys, built up edge (BUE) is likely to form on the tool rake face and result in an increase in tool wear and poor finish [14]. Machining of stainless steel are usually accompanied by a number of difficulties such as irregular wear and built up edge (BUE) on tool flank wear face and crater wear [15]. The flank wear also increase the cutting forces and also heat between tool and work piece [16].

At start of the experiment for first 150 mm length of turning, the flank wear was 76 mμ. As the turning continued for 300, 450, 600 and 750 mm, the flank wear started to increase and they are 96, 142, 144, and 187 µm respectively. The heat generated at high cutting speed was high and there is chance for the tool to hold the temperature at tool tip for the entire length of turning or turning F at cutting speed of 175 m/min, the initial flank wear as 82 µm and further continuation of turning the flank wear produced are 121, 147, 180 and 206 µm respectively. At cutting speed of 225 m/min, the flank wear are 72, 127, 150, 191 and 238 µm for 150, 300, 450, 600 and 750 mm length of turning respectively. At low cutting speed the contact between cutting edge and work piece time is more. The small work piece particles diffused on the cutting edge and formed BUE. The Figure 1 shows the flank wear at feed rate of 0.50 mm/rev and DOC of 0.50 mm for cutting speeds 125, 175 and 225 m/min. The Figure 2 shows the flank wear at feed rate of 0.10 mm/rev and DOC of 0.75 mm for cutting speeds 125, 175 and 225 m/min. The initial flank was 62 µm at the end of 150 mm length of turning. As the turning continued for 300, 450, 600 and 750 mm length, the flank wear values are 80, 138, 147 and 164 µm respectively. At cutting speed of 175 m/min, the flank wear values are 83, 114, 131, 152 and 216 µm for every 150 mm length of turning respectively. The Figure 3 shows the flank wear for feed rate of 0.125 mm/rev and 1.00 mm DOC. The flank wear start with 67 µm and increased to 87, 121, 147, 180 and 206 µm for every 150 mm length of turning respectively. At cutting speed of 175 m/min, the flank wear values are 92, 138, 145 184 and 210 µm for 150, 300, 450, 600 and 750 mm length of turning respectively. The flank wear values are 97, 107, 172, 189 and 274 µm for 150, 300, 450, 600 and 750 mm length of turning respectively. The heat is generated at high cutting speed and there by increases the flank wear to high value. The heat generated at high cutting speed would be high and tool would hold the heat at tool tip for entire length of turning. The Figure 4 shows the formation of flank wear and BUE at low cutting speed of 175 m/min and feed rate of 0.10 mm/rev and DOC of 0.75 mm. The Figure 4 shows flank wear and groves/ridges formed at cuttinh speed of 175 m/min having feed rate of 0.10 mm/rev and 0.75 mm DOC and formation of groves and ridges. The Figure 5 shows the formation shell fish flank wear at cutting speed of 175 m/min having feed rate of 0.08 mm/rev and DOC of 0.50 mm for 300 mm length of turning. The authors unable to find reason for shell fish formation. The shell fish wear vanished after 450 mm length of turning. The Figure 6 clearly depicts the formation of grooves cutting speed of 175 m/min having feed rate of 0.08 mm/rev and DOC of 0.50 at the end of the experiments. The Figure 7 shows the formation of BUE at the end of experiments for cutting speed of 175 m / min with feed rate of 0.125 mm/rev and 1.00 mm DOC. The formation of BUE was 201 µm.

4. Conclusions

The following conclusions were drawn based on the experiments conducted:

The flank wear occurred at low cutting speed with high feed rate and more depth of cut. i.e. at cutting speed of 125 m/min, feed rate of 0.125 mm/rev and DOC of 1.00 mm. The influence of tool flank wear was due to abrasive action between tool tip and cutting tool, hard carbides in the work piece material. At low cutting speed of 125 m/min. formation of built up edge was inevitable due to more contact time. The flank wear was also due to heat generated at low cutting speed. Further research can be extended on temperature measurements.

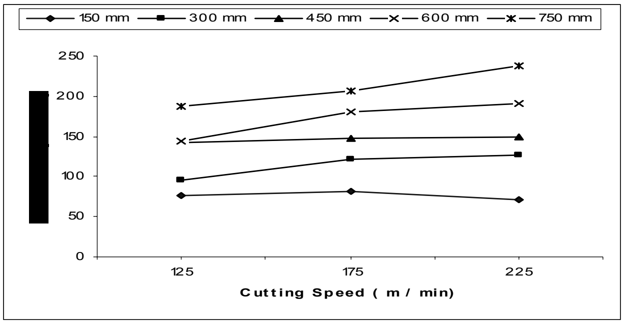

Fig. 1. Cutting speed Vs flank wear for feed rate of 0.08 mm/rev and DOC of 0.50 mm

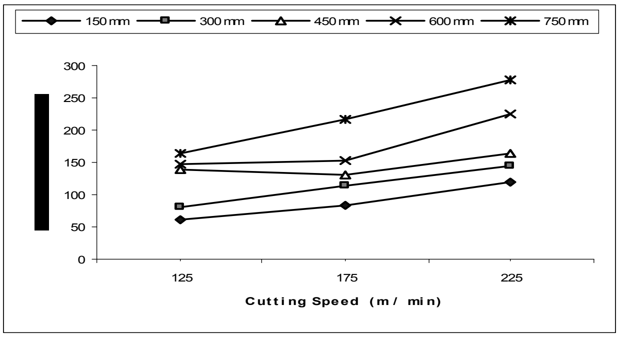

Fig. 2. Cutting speed Vs flank wear for feed rate of 0.10 mm and DOC of 0.75 mm

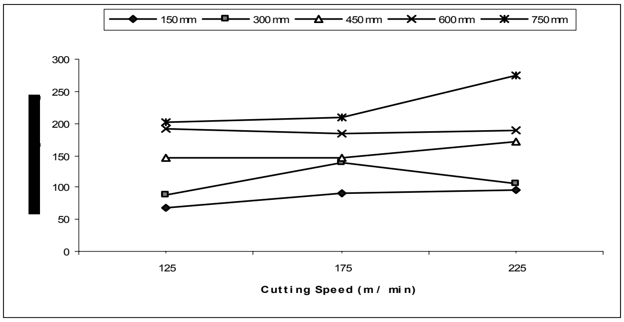

Fig. 3. Cutting speed Vs flank wear at feed rate of 0.125 mm/rev and DOC of 1.00 mm

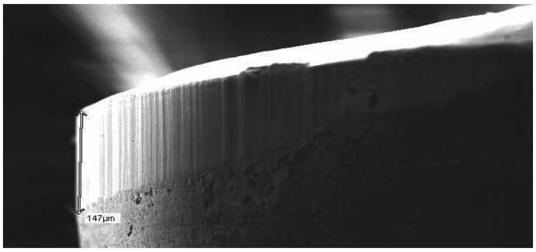

Fig. 4. SEM view on flank wear at 175 cutting speed with feed rate of 0.10 and DOC 0.75 mm

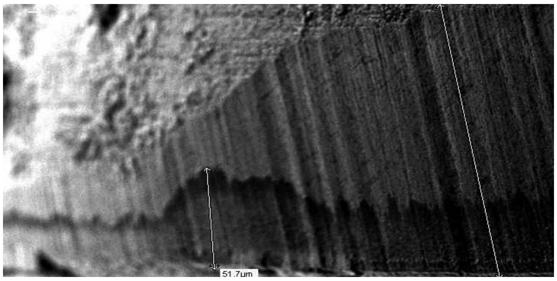

Fig. 5. SEM view on flank side showing shell fish formation at 175 cutting speed, feed of 0.08 and DOC of 0.50 mm

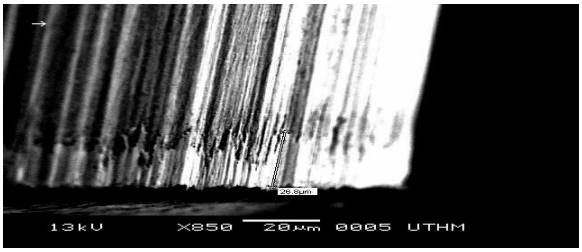

Fig. 6. SEM view grooves and ridges at 175, 0.08 and 5 mm at the end of 600 mm length turning

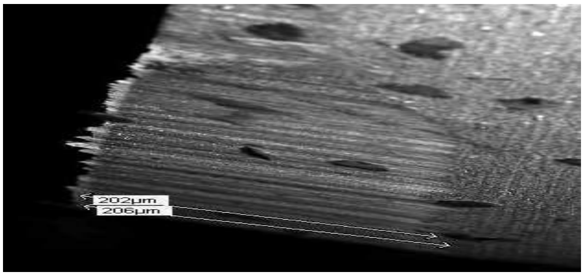

Fig. 7. SEM view flank wear with BUE at 125 cutting speed with DOC of 1.00 and feed rate of 0.125

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