Investigating Flank Wear and Cutting Force on Hard Steels by CBN Cutting Tool by Turning

SThamizhmanii* and S.Hasan

Abstract - **In this research work a series of tests were conducted in order to determine flank wear and cutting force F_Y on hard AISI 440 C martensitic stainless steel and SCM 440 alloy steels. The operating parameters are cutting speed, feed rate and a constant depth of cut to investigate the flank wear and cutting force. No cutting fluid was used during the turning process. The cutting tool used was CBN tool. The flank wear was more on CBN tool and caused by thermal softening at cutting edge. In turning alloy steel, low temperature generated and less flank wear formed. The cutting force measured on stainless steel was low due to chip softening. The less concentration of heat on the chips result more cutting force while turning SCM 440 steel. Saw tooth chips were formed in turning AISI 440 C steel in all cutting parameters and no such chips produced by SCM 440 steel.**

Key words: Built –up- edge**,** Flank wear, Cutting force, Saw tooth chips, Temperature**,**

I. INTRODUCTION

The most emerging trend of the modern metal cutting operations is to increase the material removal rate with good surface roughness and high machining accuracies. Turning difficult to cut (DTC) materials using existing conventional techniques is an un-economical as the turning process results in high tool wear, takes longer time [1] and require high cutting force. The stainless steel, titanium and Inconel are DTC and they are high strength materials. Most of the mechanical energy used to form the chip becomes heat, which generates high temperatures in the cutting zone [2]. The generation of heat was very high while turning these materials due to low thermal conductivity, high work hardening rate, high viscosity, tendency to form built-up-edge (BUE) at tool edge compared to other alloy steels. The AISI 440 C is a hardenable martensitic stainless and SCM 440 is alloy steel considered for turning. The stainless steels affect the machinability and surface roughness, BUE, tool life, chip formation, and cutting forces, are the criteria for machinibility [3].

Both authors are working in the Faculty of Mechanical and Manufacturing Engineering, Universiy Tun Hussein Onn Malayisa, 86400, Parit Raja, Batu Pahat, Johor, Malaysia.
* mail: thamizhmaniis@yahoo.com

The temperature at cutting zone influences the cutting forces and tool flank wear. In this study, the cutting speed, feed rate and a constant depth of cut was used as operating parameters. BUE and irregular wear are often faced in machining operations on stainless steels than alloy steel. High temperatures at the tool–chip interface result in an increase of diffusion and chemical wear [4]. Turning of AISI 440 C requires high cutting forces than SCM 440 materials. The various forces acting act on single point tool materials is shown in the figure 1. The force F_Y is considered as cutting force which deforms the chips. It was not possible to find reasons for variation in cutting force for all the operating parameters. The hard martensitic stainless steel generates more heat at cutting zone than SCM 440 steel. This was due to low thermal conductivity of the stainless steels. After turning process, it was possible to handle AISI 440 C stainless steel work piece by naked hand than SCM 440 steel. It was an indication that stainless not much affected by heat. The retention of heat by stainless steels was less where as alloy steel it was more. Measuring the cutting forces directly by dynamometer is more accurate than calculation [5]. The knowledge on cutting forces is a pre-requisite on cutting temperatures estimation, tool life prediction, cutting process and chatter analyses [6].

II. EXPERIMENTAL PROCEDURES

Investigation by CBN tool on hard martensitic AISI 440 C stainless steel and SCM 440 was carried out by turning process. The turning experiments were performed on N. C. Harrison alpha 400 lathe. The work piece materials were 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 was done by induction hardening process at out side source. The hardness of the materials was maintained between 45 to 55 HRC. The turning was carried for a length of 150, 300, 450, 600 and 750 mm. Turning by each cutting edge was named as trail 1, 2, 3, 4 and 5. The cutting edges were repeated for 5 times with corresponding cutting parameters. The cutting force was measured by Kistler Force measurement Type 9265B with multi channel charge amplifier Type-5019A and data acquisition system. The tool flank was measured using Scanning Electron Microscope (SEM) Joel 6380 LA. The cutting tool was manufactured by Mitsubishi and named as NP-TNGA1600412G3-MB8025. The cutting speeds are 100,

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125, 150, 175 and 200 m/min having feed rate 0.10, 0.20 and 0.30 mm/rev. with constant depth of cut of 1 mm.

III. RESULTS AND DISCUSSION

A. Cutting force FY.

In any metal cutting, maximum amount of heat generated in the cutting zone is carried away by chip and partial amount of heat was retained by work piece. This is applicable to alloy steels where as in stainless steels very less amount of heat retained in work piece. The presence of heat at cutting zone softens the chips in a machining process. The softening effect plasticize the chips and less cutting forces are recorded. In turning stainless steels at low cutting speed and feed rate, the contact time between tool tip and work piece was more which rub the work piece. This rubbing action generates more heat at cutting zone and carried away by the chips. The heat generated by AISI 440C was more and plasticize the chips. Due to low thermal conductivity of AISI 440 C material and plasticizing effect, low cutting force recorded. In turning SCM 440 steels, due to conduction of heat by work piece plasticizing of chips was less. This required more cutting force. The figure 2 shows the number of trails against cutting force FY at cutting speed of 100 m/min having feed rates of 0.10, 0.20 and 0.30 for both AISI 440 C and SCM 440. The cutting forces are increased on each trail for AISI 440 C than SCM 440. The figures 3, 4, 5 and 6 represent graphs at cutting speed 125, 150, 175 and 200 respectively for AISI 440 C and SCM 440 materials against cutting force FY. At high cutting speed and feed rate, the cutting force required was more for SCM 440 steels. The cutting force required for AISI 440 C was considerably low. Tool flank wear is strongly influenced by the interactions between cutting tool and work piece in the form of contact stress and cutting temperature [7]. The lower cutting force results in less distortion of work piece which improves surface roughness [8]. As the flank wear increased the cutting force tend to increase and reached maximum value for the maximum flank wear for stainless steel. The maximum cutting force of 464 N was recorded at cutting speed of 150 and 175 m/min having feed rate of 0.30 mm/rev. This was due to high formation of flank wear.

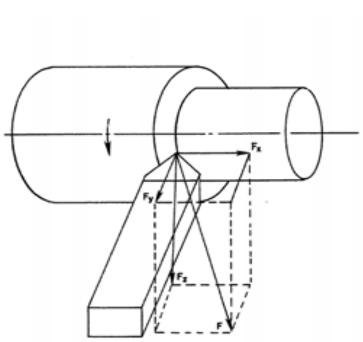

Figure1. Single point tool showing 3 three forces acting.

At cutting speed of 150 and 175 with feed rate of 0.30 mm/ rev, the flank wear were high and hence high cutting force recorded.

B. Tool flank wear

The wear mechanisms in cutting tools are very complex. When turning at high speeds by dry turning, high temperature was generated at tool tip and work piece contact. A particular form of chemical wear, the dissolution and diffusion of tool material into the work piece material, becomes the predominant mode of tool wear at high temperature [9]. The flank wear and crater wear are the two principal wears occurring on any turning process which affect the machining surface. The heat generation and the plastic deformation induced during machining affect the machined surface and induced quick tool wear [10]. Konig et al [11] found that different work piece materials such as hardened alloy steels, case hardened steels, nitriding steel, high speed steels, with same hardness of 62 HRC, when machined under same cutting conditions showed varying tool wear rates. Adhesion wear occurs when hard inclusions of work materials or escaped tool particles scratch the flank side as they move across the contact area as well [12]. The figure 7 shows flank wear against cutting speed of 100 for both AISI 440 C and SCM 440 with feed rate of 0.1, 0.20 and 0.30 mm/rev. The figure 8, 9, 10, and 11 shows the flank wear against cutting speed of 125, 150, 175 and 200 having feed rates of 0.10, 0.20 and 0.30 mm/rev. respectively. The formation of flank wear was not gradual and varied from parameter to parameter. The reason for flank wear was due to increase in temperature at cutting zone on stainless steel which softens the cutting edge and abrade more. In case of SCM 440 material, the flank wear measured was low in all operating parameters due to less heat at cutting zone. The flank wear measured were correspondingly high for AISI 440 C than SCM 440 materials. The maximum flank wear occurred at cutting speeds of 175 and 200 m/min. feed rate of 0.30 and 0.10 mm/rev respectively for stainless steel. The figure 12 shows SEM view on flank wear while turning AISI 440 C material at cutting speed of 175 with feed rate of 0.30. The corresponding values were 253 and 238 microns for AISI 440 C. The SCM 440 steel produced less flank wear than AISI 440 C. The maximum flank wear measured at cutting speed of 175 m/min at low feed rate of 0.10 for SCM 440 and the value was 155 microns. The figure 13 shows SEM view on flank wear for SCM 440 steel at cutting speed of 175 with feed rate of 0.10. The figure 14 is SEM view on notch wear occurred at cutting speed of 200 having feed rate of 0.30 while turning AIAS 440 C.

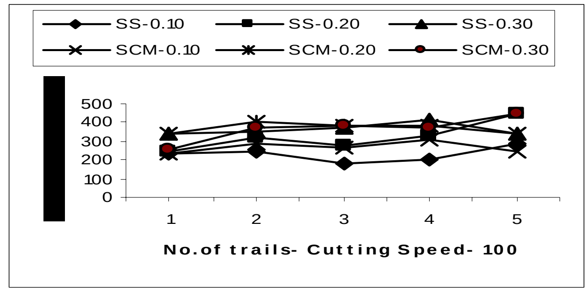

Figure 2. Cutting Speed at100 Vs Cutting - Force FY –Trail 1.

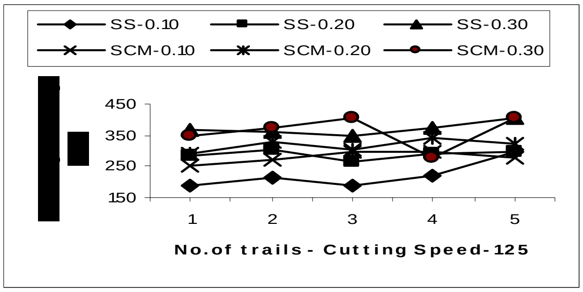

Figure 3. Cutting Speed at 125 Vs Cutting force FY -Trail 2.

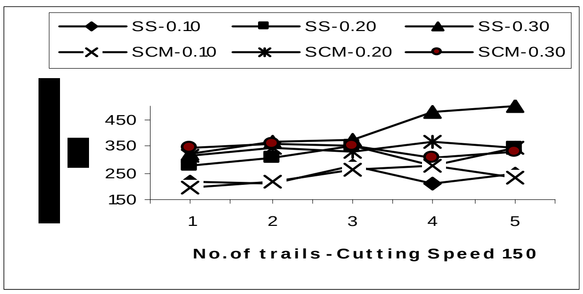

Figure 4. Cutting Speed at 150 Vs Cutting Force FY –Trail 3.

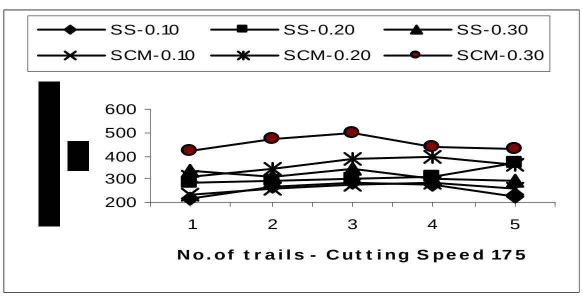

Figure 5. Cutting Speed at 175 Vs Cutting Force FY-Trail 4.

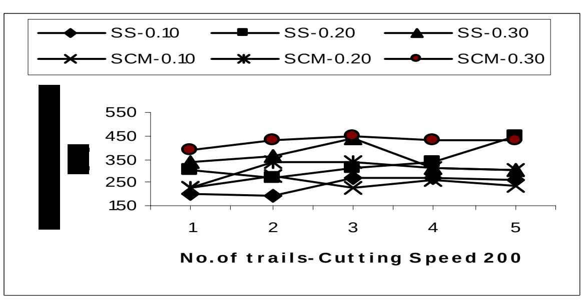

Figure 6. Cutting Speed at 200 Vs Cutting Force FY-Trail 5.

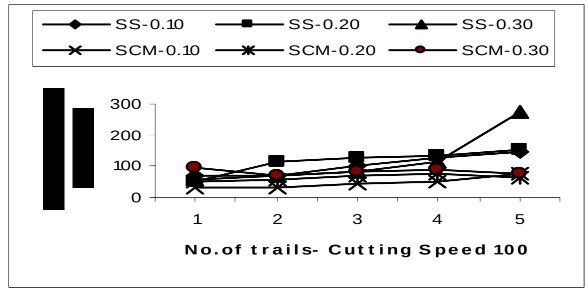

Figure 7. Cutting Speed at 100 Vs Flank wear Trial 1.

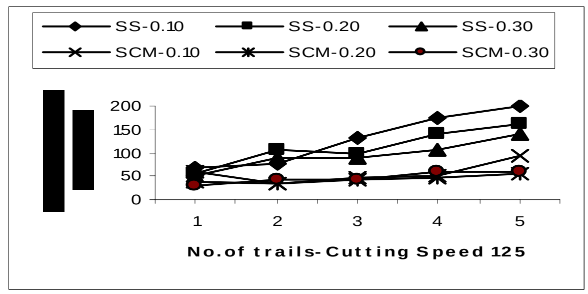

Figure 8.Cutting Speed at 125 Vs Flank wear –Trail 2.

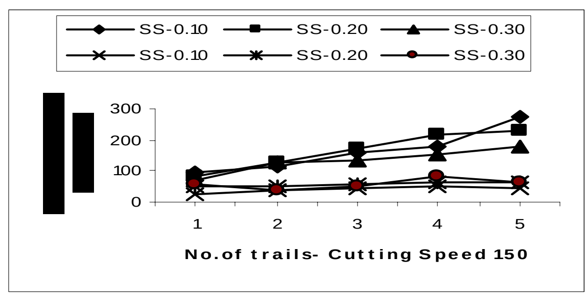

Figure 9.Cutting Speed at 150 Vs Flank wear –Trail 3.

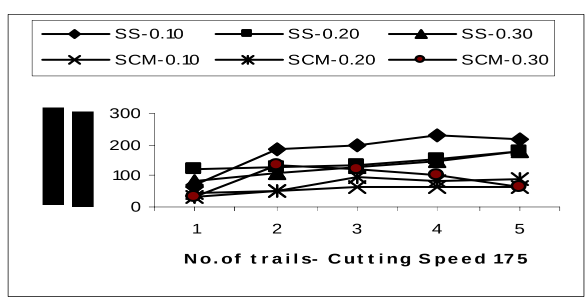

Figure 10. Cutting Speed at 175 Vs Flank Wear Trail 4.

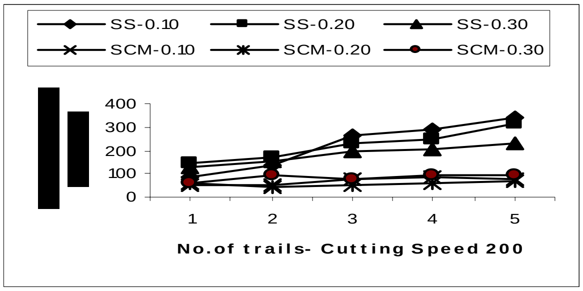

Figure 11. Cutting Speed at 200 Vs Flank Wear Trail 5.

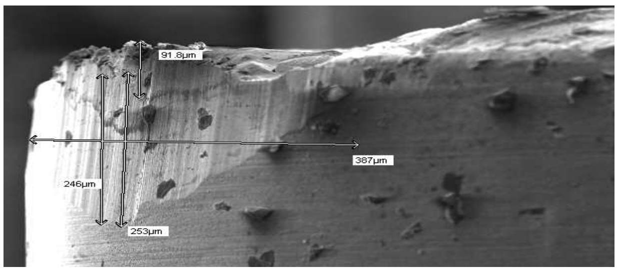

Figure 12. SEM view on flank wear on AISI 440 C material at cutting speed of 175 and feed rate of 0.30.

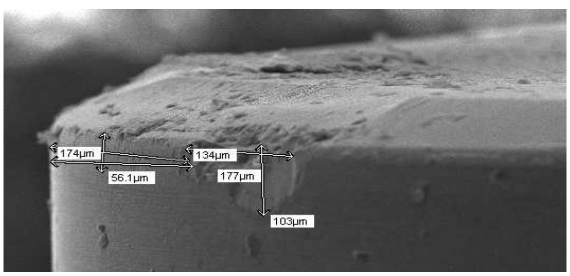

Figure 13. SEM view on flank wear on SCM 440 material at cutting speed of 175 and 0.10 feed rate.

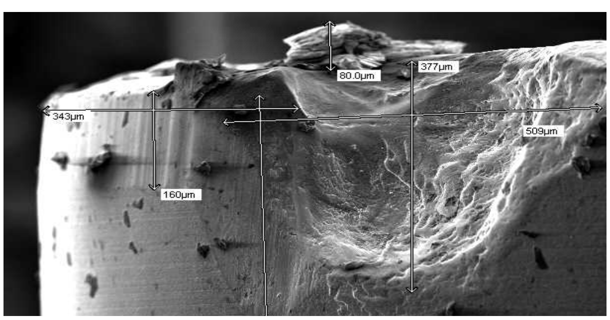

Figure 14. SEM view on chipping at cutting speed of 200 and feed rate of 0.30.

B. Built up edge (BUE)

The figure 12 shows formation of flank wear and BUE while turning AISI 440 C material. In general, as the cutting speed increased, the friction between chip and tool will increase and when this becomes large enough to cause a fracture in the

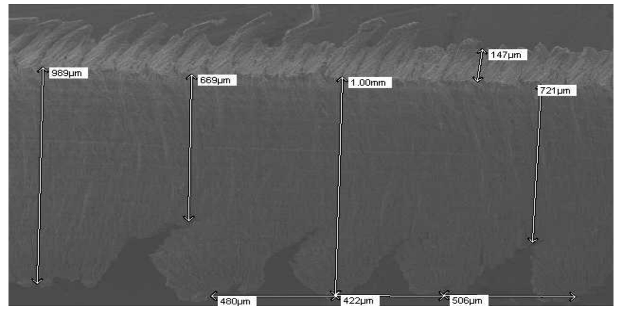

Figure 15. SEM view on saw tooth formation cutting speed of 125 and feed rate of 0.30.

vicinity of the tool face, a built up edge is formed. The BUE theory states that a rough surface obtained at lower cutting speed and a smooth surface at higher speed. Some researches have stated that the BUE may be eliminated by increasing cutting speed and feed rate [13]. The BUE formation and tearing off during cutting can be also leads to the machining forces instability, which results in cutting edge chipping. The BUE formed in each cutting edge from the beginning of the tests on AISI 440 C than SCM 440 material, it formed only at higher cutting speed of 175 having feed rate of 0.30 for SCM 440. The formation of BUE was inevitable in turning stainless steel due to the welding characteristics and high viscosity. Maximum BUE of 92 micron was formed at cutting speed of 175 m/min having feed rate of 0.30 mm/rev. A.Senthilkumar et al [14] observed that saw tooth chips are formed while machining martensitic stainless steel and produced notch wear. Maximum BUE occurred at 175 cutting speed having feed rate of 0.30 mm/rev and cutting force was 464 N. The figure 15 shows the formation of saw tooth chip and are formed in all cutting parameters while turning AISI 440 C. No such chips formed by SCM 440 materials. At lower cutting speeds, BUE becomes stronger than higher cutting speeds. At higher cutting speeds, cutting zone temperature increases and this, in turn, softens and decreases strength of BUE [15]. The figure 15 shows the heat affected by saw tooth chip which is black and bright surface is not much affected by heat.

IV. SUMMARY

The flank wear and cutting force using CBN cutting tool on AISI 440 C and SCM 440 were investigated.

1. The formation of flank wear occurred was due to thermal softening of cutting edge by the heat generated by AISI 440 C material. The heat generated by SCM 440 was shared by work piece and chips, less thermal softening occurred and less flank wear formed. The hard particles and abrasion of the work piece was also responsible for flank wear formation.
2. There were direct relationship between flank wear and cutting force. When the flank wear was more, more cutting force required for both materials. The BUE formation was very strong in low cutting speed than at

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high cutting speed. At high cutting speeds, the BUE weakened and disappeared.

3. The low in cutting force was due to softening of chips at cutting zone by AISI 440 C steel than SCM steel. Maximum cutting force was recorded for SCM 440 in all the test results than AISI 440 C. It was due to heat shared by the chips and work piece materials.
4. The stainless steel produced saw tooth chips in all cutting parameters and reasons for formation under investigation. In turning SCM 440, no such formation.
5. The failure mode of cutting tools was due to chipping.

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