Experimental Investigation on the Effect of Workpiece Hardness and Cutting Speed on Surface Roughness in Hard Turning With CBN Tools

E.D.Derakhshan , A.A.Akbari

Abstract— **Hard turning is considered as a new machining process aimed at turning hardened steels with high surface qualities. This process is a good alternative for many grinding applications which were previously done through traditional machining processes. The goal of this paper is to test the empirical feasibility of using this new method instead of grinding in many industrial applications, and to determine the effects of independent parameters such as hardness of parts and cutting speeds on the surface quality and tool wear in hard turning operations. Hence parts made of AISI 4140 alloyed steel are exposed to different thermal treatments to achieve different hardness rates in the range of hard turning operations. These parts are then machined with CBN cutting tools and CNC lathing machines at different cutting speeds, and results are compared in terms of surface roughness.**

Index Terms— **CBN Tool, Hardened Steel, Hard Turning, Heat Treatment, Surface Roughness**

I. INTRODUCTION

Machining of hardened steels is particularly common in bearing and automotive industries. In abrasive processes such as grinding, the surface has to be ground to required dimensions and finished to the desired and final geometry [1]. The new advancements in machine tools technology and use of new cutting tools provide the opportunity to take loads from hardened steels through processes such as lathing and milling. Recent achievements have made it possible to replace hard turning by modern turning (lathing) machines and new cutting tools for many industrial applications.

Hard turning is a good alternative to applications not requiring very high quality finishing, obviously works requiring high tolerances see grinding as their first choice [2]. Hard turning of highly hardened parts is a new approach in machining science aimed at increasing productivity and yield through reducing production time and costs of the process. This method has been introduced as a suitable alternative to grinding of hardened parts. Through this method the finishing process is done at the same time as the main machining process (i.e. roughing). The term 'hard turning' is used for lathing of highly hardened steels, over 45 HRC {[1],[2],[3],[4],[5],[6],[7],[8]}. Materials used for hard turning may undergo thermal treatment or case hardening. These types of steel constitute a very important class of engineering materials because of their advanced tensile and wear resistance [1]. The use of CBN cutting tools along with other advancements of machine tools have resulted in the developing of this method. The use of these tools makes it possible to turn hard alloys steels with high degrees of hardness at high turning speeds. The range of applications of hard turning is quite broad and is usually defined based on part requirements and specifications, surface tolerance, surface finish, and machine tools because every machine is not suitable for this sort of operations.

Advantages of this method include high flexibility, reduced working cycle times, no need to use environmentally high risk lubricant, soft and hard turning on the same machine, higher yield per matter, lower costs of tools and machines, and performing several tasks with a simple machine configuration, and higher productivity and yield.

Tolerances required for industrial parts need a finishing process after thermal treatment. This has been done by grinding for years and the hard turning process should be capable of producing parts with high geometric accuracy and surface roughness. Liu and Mittal turned some parts by hard turning and low surface quality in a range of 0.045 – 0.197 μm [9]. They also measured the quality of needed surfaces for ball bearings to less than R_a = 0.2 μm after surface finish. Similar results were obtained by Jochmann and Wirts [10]. Abrao and Aspinwall successfully produced surfaces with R_a = 0.14 μm finish [11]. Other tests were run by coated tools in hard turning of steel bars of AISI 4340 type, resulting in a bar with average tool life of 20 minutes for each cutting edge at V = 150 m/min, f = 0.15 mm/rev, and DOC = 0.25 mm and workpieces with surfaces of R_a = 0.5–0.7 μm comparable to a good grinding process [12]. Rech et al studies the process of surface finishing of bearing steel AZSE 52100 by using ceramic and PCBN tools. Hard turning by both tools produced surfaces with roughness of R_z = 1–2 μm and R_a = 0.1–1 μm [13]. Wanat et al studied the roughness of surfaces produced through hard turning of low-chrome alloyed steel by ceramic tools having wiper or normal geometries. Results indicated that normal geometry tools created a roughness of R_z = 1.55 μm and R_a = 0.28 μm with a feedrate of 0.04 mm/rev while wiper geometry tools created a roughness of R_a = 0.25 μm and R_z = 1.62 μm with a feedrate of 0.1 mm/rev [14]. Rigal et al conducted empirical research on hard turning of tempered steel 100CR6 by CBN tools in which surface roughness did not exceed R_a = 0.55 μm [15].

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II. EXPERIMENTAL PROCEDURE

To determine the effects of workpiece hardness and cutting speed on surface roughness of steel bars of AISI 4140, which is given in details in Table. I, the pieces are exposed to thermal treatments such as quench and temper so that their hardness comes into the range of hard turning (details of the thermal treatment process are given in Table. II). There had 5 workpieces with 5 different hardnesses in range of hard turning (45-65 HRC with step 5). Hard turning used for every parts in situation that feedrate and depth of cut were constant but cutting speed is changed and also two kinds of CBN tools are used. The tests have been done four times for each part with three cutting speeds and constant feedrate and depth of cut (respectively a_f = 0.1 mm/rev, a_p = 0.2 mm). Sample diameter of parts and length are 24 mm and 200 mm respectively.

High hardness and high strenght of the workpieces that resulting in high temperatures on the cutting edge and its penetration between the tool and the chips, and the wear of the tool nose, it could be said that wear resistance and chemical stability are among the most important features of any materials used for hard turning. CBN tools have high thermal hardness and wear resistance scores and rank among the very best tools for such machining processes. Major advantages of CBN tools are maintaining their hardness even at very high temperatures, low solubility, good fracture toughness and many other advantages. Tow kind of tools used in this study, CB50 CNMW 060408 and CB7020 TNGA 160404 with two different nose radius that made by Sandvik Company.

Turning operations were performed on a Challenger CNC machine. After all phases of turning were completed the pieces underwent tests for their roughness in lab conditions at a temperature of 26°C and a humidity of 34% according to reference standard D2N EN ISO 4287 by using a roughness measuring machine. The movement course of the machine was 0.8 mm (basic span = 0.8 mm) that detecting the surface roughness in each 40 mm. For each 5 parts with different hardness after three times measuring for every repeat their average was introduced as surface roughness. Our turning operations were done without any cooling fluid (in dry conditions). Cutting conditions and obtained results are given in Table. III.

An optical microscope to be magnified until 1000 times used for getting photo from cutting edge of tool for determining tool wear.

Table I. Chemical composition of alloy steel AISI 4140

Name	% C	% Si	% Mn	% P	% S	% Cr	% Mo
AISI 4140	0.38-0.45	≤ 0.4	0.6-0.9	≤ 0.35	≤ 0.035	0.9-1.2	0.15-0.3

Table II. Different heat treatment process for AISI 4140

Heat Treatment Process	Temperature °C
Hot Working	850 - 1050
Soft Annealing	680 - 720
Normalizing	840 - 880
Harding Temperature for Quenching in Oil Or Water	820 - 860
Temper	540 - 670

Table III. Cutting conditions and obtained results

Number of Row	Types of Tools	Hardness H (HRC)	Spindle Speed N (rpm)	Cutting Speed V (m/min)	Roughness R_a (μm)	Roughness R_z (μm)
1	CB7020	45	1800	125	0.375	2.425
2			2200	152	0.385	2.2
3			2500	173	0.452	2.587
4	CB50	45	1800	125	0.24	1.43
5			2200	152	0.277	1.72
6			2500	173	0.323	1.77
7	CB7020	50	1800	125	0.167	1.025
8			2200	152	0.702	3.8
9			2500	173	0.207	1.25
10	CB50	50	1800	125	0.294	1.6
11			2200	152	0.269	1.65
12			2500	173	0.24	1.54
13	CB7020	55	1800	125	0.425	2.437
14			2200	152	0.387	2.437
15			2500	173	0.245	1.692
16	CB50	55	1800	125	0.232	1.31
17			2200	152	0.207	1.11
18			2500	173	0.175	1.25
19	CB7020	60	1800	125	0.395	2.527
20			2200	152	0.435	2.612
21			2500	173	0.485	2.932
22	CB50	60	1800	125	0.234	1.44
23			2200	152	0.3	1.71
24			2500	173	0.222	1.22
25	CB7020	65	1800	125	0.22	1.437
26			2200	152	0.222	1.3
27			2500	173	0.477	2.345
28	CB50	65	1800	125	0.665	3.05
29			2200	152	0.544	3
30			2500	173	0.642	3.46

III. RESULTS AND DISCUSSION

Hardened workpieces ranging between 45-65 HRC, having a step of 5, and error ratio of ±1 HRC were turned by a CNC machine after preparation so that the effects of changes in hardness and cutting speed on surface roughness and tool wear produced by machining operations could be analyzed. Depth of cut, feedrate, and cutting speeds are determined based on type of tool, optimized values quoted in manufacturer catalogues, and conditions of CNC machines.

According to the Table. III, the minimum roughness (R_a) was gained through machining 50 HRC workpiece with CB7020 tool. Fig. 1 and Fig. 2 show the roughness values with respect to changes in cutting speed and hardness. There are many items that effected on surface roughness. In here, we counted many of these items. When the turning operation was been done the temperature of cutting area extremely arise because the workpieces hardness are very high. According to this temperature, we had a thermal softening in cutting area (Between tool edge and surface of workpiece) that made easier the plastic deformation for chips. The hard particles in workpieces effect on tool wear that this reason made surface roughness arise.

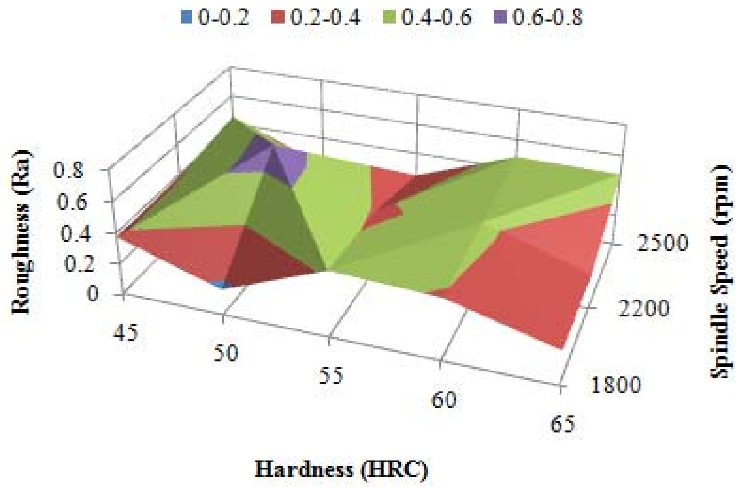

Fig.1. The changes of Hardness and Spindle Speed on Surface Roughness with CB 7020

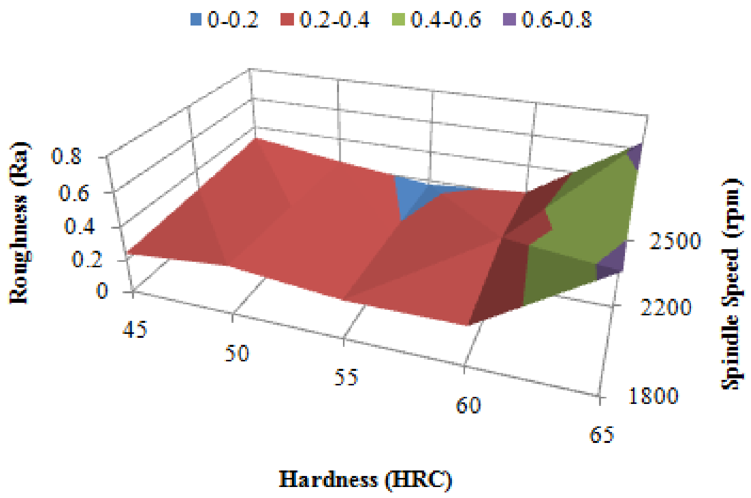

Fig.2. The changes of Hardness and Spindle Speed on Surface Roughness with CB 50

Impurities of workpieces also effect on surface roughness, because engagement between tool and these impurities cause wear in cutting edge of tool.

The most important of wear mechanisms consist of adhesive wear, abrasive wear, erosive wear, diffusion wear, corrosive wear and fracture wear. Majority wear mechanism that shown in this research depends on abrasive wear because workpieces were very hard. This kind of wear created when hard particles are sliding and moving on cutting edge of tool (Fig. 3).

IV. CONCLUSION

The following results were obtained from hard turning of hardened alloyed steel AISI 4140 with hardnesses of 45-65 HRC at various cutting speeds.

- The most important deference between this experimental work with other researches is in number of workpieces (5 workpieces) used in tests until to specify the effect of hardness values on surface roughness.
- Best surface quality in hard turning with CB50 tool obtained for 55 HRC workpiece by machining at 2500 rpm with R_a=0.175 µm.
- In the hardness range of 45-60 HRC with CB50, surface roughness in demanded cutting conditions does not exceed R_a=0.323 µm.
- Best surface quality in hard turning with CB7020 tool obtained for 50 HRC workpiece by machining at 1800 rpm with R_a=0.167 µm.
- Increase of cutting speed had a tremendous effect of resulting surface roughness.
- Given the results obtained for surface roughness of hardened work pieces it is possible to compare and substitute this process with and instead of grinding for similar applications.

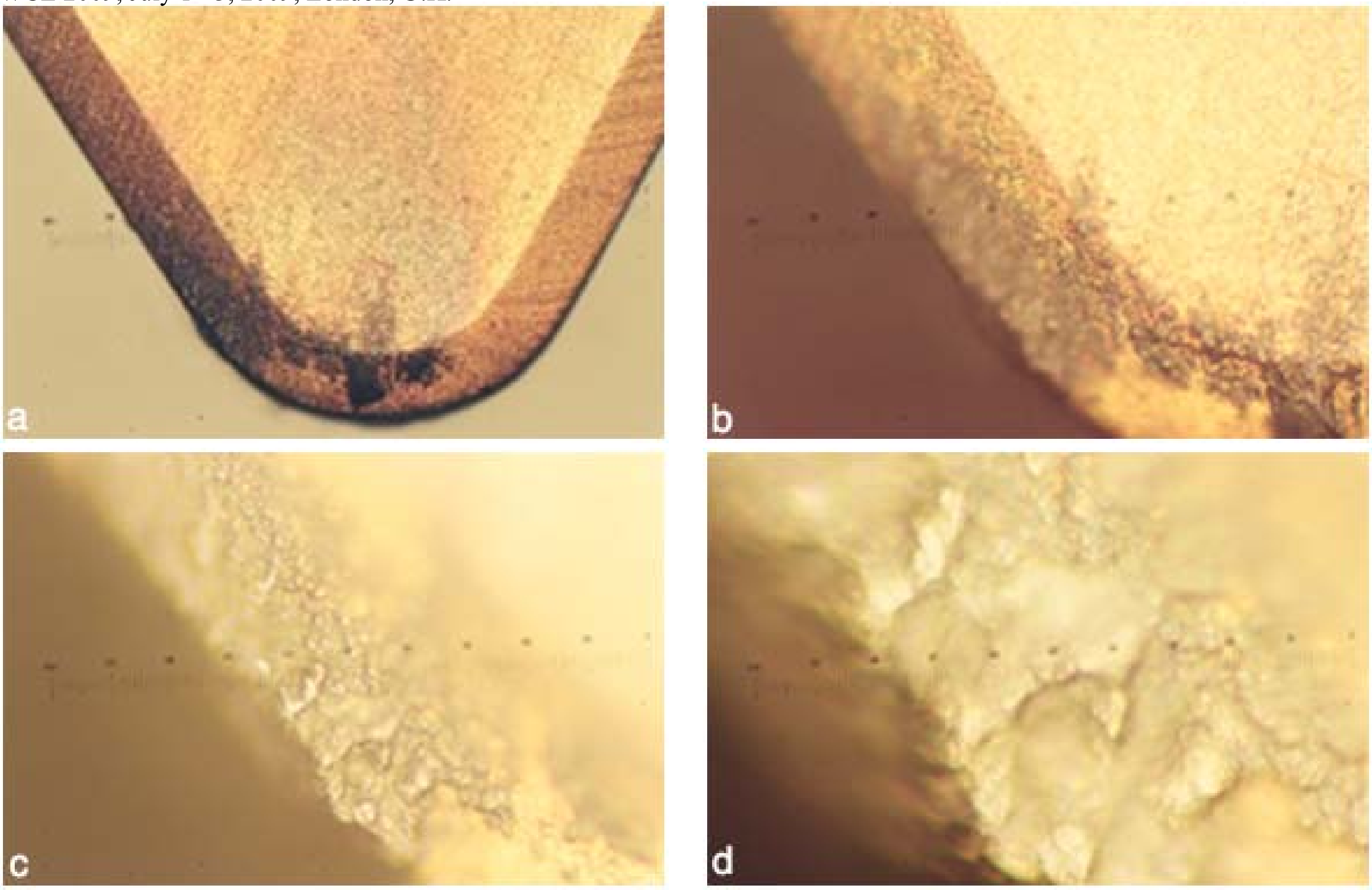

Fig.3. Tool Wear in Cutting Edge a) Magnification ×100, b) Magnification ×200, Magnification ×400, d) Magnification ×1000

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