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PERFORMANCE EVALUATION OF UNCOATED CARBIDE CUTTING TOOLS IN TURNING NST 37-2 STEEL

D.A. Fadare[1] and T.B. Asafa[2]

[1]*Department of Mechanical Engineering, University of Ibadan, P.M.B. 1, Ibadan, Nigeria*
E-mail: fadareda@yahoo.com; Tel: +234 (0)802 3838 593
[2]*Department of Mechanical Engineering, Ladoke Akintola University of Technology, P.M.B. 4000, Ogbomoso, Nigeria*

ABSTRACT

In metal cutting operations, performance of the cutting tool is the major determinant of the productivity, functionality and production cost of the machined component. In this work, the performance of uncoated cemented carbide tools with International Standard Organisation (ISO) designation SNMA120406 was evaluated for turning of NST 37.2 steel. Turning operations were conducted on M300 Harrison type lathe driven by 3.0 hp Kapak induction motor. The cutting conditions used were: cutting speed, 20.42, 29.06 and 42.42 m/min; feed rate, 1.0, 1.8 and 2.2 mm/rev; and depth of cut, 0.2, 0.4 and 0.6 mm under dry machining. Results showed that both flank and nose wear increased with increase in number of pass, cutting speed, depth of cut and feed rate. The optical surface roughness of the machined workpiece varied from 0.658 - 0.924 and case hardening of the machined surface was observed. Segmented chips with smaller coil radii, which were less voluminous and more manageable were produced at all cutting conditions investigated. Chip breakability tends to increase with increase in cutting speed. The use of uncoated carbide tools has proved to enhance the productivity and surface quality in turning of NST 37-2 steel.

Keywords: Tool performance, uncoated carbide, cutting tools, machining, NST 37-2 steel

1.0 INTRODUCTION

NST 37-2 steel is one of the commercial plain carbon steel grades produced by the Delta Steel Company (DSC) in Aladja, Delta State, Nigeria [1]. It is commonly used in Nigeria for manufacturing of machine parts and as structural member in building, road and bridge construction. Presently, in Nigeria, machined components are commonly produced using conventional High Speed Steel (HSS) cutting tool, which has short tool life, poor surface finish and continuous chip formation in high-speed machining of difficult-to-cut workpiece materials. Hence, productivity is impaired as manufacturing time and the cost of production increased when HSS tools are used. The surface finish of the machined components is also impaired with the used HSS tools when components are machined at high cutting speeds. In the current manufacturing age, the need to optimize machining operations via selection of most appropriate cutting tool is an essential requirement towards reduction of manufacturing time and cost. This has led to the development of harder and tougher cutting tool materials such as ceramics and carbide grade tools [2, 3]. Coated and uncoated carbide tools are globally used in machining based industries and provide best alternatives for turning operations [4]. Uncoated carbide tool can maintain high hot hardness at a temperature as high as 1200°C [5] and can therefore be used at higher cutting speeds compared to HSS or cast alloy tools.

Wear characterization and tool performance of sintered carbide inserts during automatic machining of AISI 1045 steel has been reported by Rogante [6]. The study showed that the coated inserts permit approximately 50% longer machining time, a higher wear mark width and reduced applied power consumption, compared with uncoated inserts. Sharif and Rahim [7] also evaluated the performance of coated and uncoated carbide tools when drilling titanium alloy Ti-6A14V. Their study showed that non-uniform flank wear, chipping and catastrophic failure were the dominant modes of tool failure for both coated- and uncoated-drills. At all cutting speeds tested, TiAlN-coated-drill significantly outperformed uncoated-drill in terms of tool life and surface finish. The effect of cutting speed on the performance of the uncoated-carbide drill was less significant at all cutting speed tested [7]. Nikhil *et al.* [8] investigated the wear behaviour of uncoated carbide inserts under dry, wet and cryogenic cooling conditions in turning C-60 steel and reported a substantial reduction in tool wear, which enhanced the tool life, dimensional accuracy and surface finish.

However, in Nigeria, as a developing nation, where machining workshops are solely small scale business, machinists are not yet exposed to the use of modern cutting tools. To the best of the authors' knowledge, the performance of these modern cutting tools such as carbide tools in machining of steel grades produced in Nigeria have not been evaluated.

The present study aimed at evaluating the performance of uncoated carbide cutting tools in turning of NST 37-2 steel in terms of the tool wear characteristics, surface integrity, chip morphology and spindle current.

2.0 Materials and Method

2.1 Workpiece material

Samples of fully annealed NST 37-2 steel bars with 25 mm diameter and 10 m length were obtained from Delta State Company (DSC), Aladja, Nigeria. The chemical composition and the mechanical properties of the steel samples are given in Tables 1 and 2, respectively.

2.2 Cutting tool and tool holder

Uncoated cemented carbide inserts produced by Sandvic Coromant® with ISO designation SNMA120406 were used. The insert has a square shape with zero clearance angle and inbuilt chip breaker. It was rigidly mounted on a tool holder with ISO designation PSBNR 3225P15.

2.3 Machining Operations

Straight turning operations were carried out on M300 Harrison-type lathe driven by 3 hp Kapak inductions motor with speed range of 40 and 2500 rpm. Cutting conditions typical of what are used in the machining industries were used in the machining trials. The cutting conditions used in the investigation are listed in Table 3. The cutting parameters: cutting speed (v); feed rate (f) and depth-of-cut (d) were investigated at three different levels in a 3^3 full factorial experimental design (27 experiments)

Table 1: Chemical Composition of NST 37-2 Steel

Element	Composition by weight (%)
C	0.331
S	0.011
Si	0.150
Mn	0.690
P	0.018
Fe	98.800

(Source: Asafa [9])

Table 2: Mechanical Properties of NST 37-2 Steel

Properties	Average value
Yield Strength (MN/m^2)	245.41
Tensile Strength (MN/m^2)	342.33
Elongation (%)	18.48
Reduction in Area (%)	15.05
Young Modulus (GPa)	198.50
Hardness (BHN)	48.50
Density (kg/m^3)	8.15 x 10^{-3}

(Source: Asafa [9])

Table 3:Cutting conditions

Factor	Level		
	(1)	(2)	(3)
v (m/min)	20.4	29.1	42.4
f (mm/rev)	1.0	1.8	2.2
d (mm)	0.2	0.4	0.8

The cutting tests were carried out without the application of coolant. For each experiment, eight passes with 50 mm length of cut were machined and the spindle current, tool wear (nose and flank), surface integrity (roughness and microstructure) of the machined surface were measured. Spindle current was measured with digital multimeter (DSS, AK28M Model, England) connected to a computer. The tool wear lengths for nose and flank wear and the digital surface roughness of the machined surface were measured by means of the machine vision system [10, 11]. The schematic of the experimental setup is shown in Figure 1.

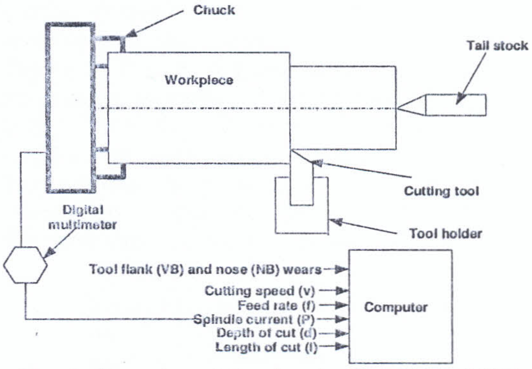


Fig. 1: Experimental setup for turning of NST 37-2 Steel

3.0 Results and Discussion

3.1 Evaluation of Tool wear

A typical tool wear image generated at cutting speed of 42.4 m/min is shown in Figure 2. Presence of chipping, attrition and abrasion were observed on the carbide tools during turning of NST 37-2 steel under the conditions investigated in this study.

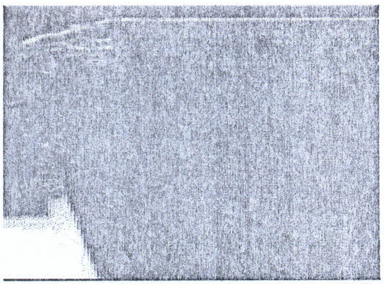


Fig. 2: A typical image showing the tool flank wear generated at cutting speed of 42.4 m/min, feed rate of 1.8 mm/rev and depth-of-cut of 0.8 mm

The tool wear lengths generated at cutting speed of 20.4 m/min, feed rate of 1.0 mm/rev and depth-of-cut of 0.8 mm is shown in Fig. 3. It can be observed that both flank and nose wear increased with increase in length-of-cut from 0.20 - 0.75 mm and 0.02 - 0.07 mm, respectively

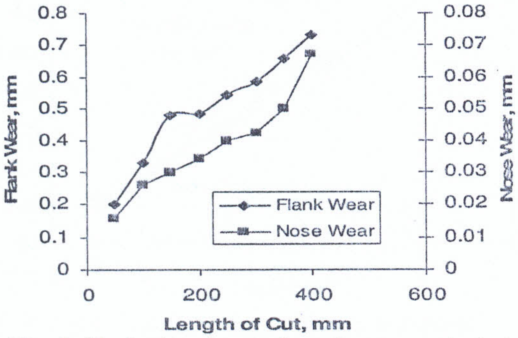


Fig. 3: Typical tool wear lengths generated at cutting speed of 20.4 m/min, feed rate of 1.0 mm/rev and depth-of-cut of 0.8 mm

The effect for cutting speed on tool wear for a typical cutting condition with feed rate of 1.0 mm/rev and depth-of-cut of 0.4 mm is depicted in Figure 4. It can be seen that increase in cutting speed led to increased tool wear. The flank wear increased from 0.32 to 0.39 as cutting speed increased from 20.4 to 29.1 m/min and thereafter remained fairly constant up to cutting speed of 42.4 m/min. This can be attributed to the fact that more force is exerted on cutting tool at higher cutting speed leading to more wear, however the flank wear rate dropped at cutting speed of 42.4 m/min because of softened workpiece material occasioned by higher cutting temperature generated, giving cutting tool an easier passage. A similar trend has been reported by Ezugwu *et al.* [12] when machining Inconel 718 alloy using triple (TiCN/Al_2O_3/TiN) PVD-coated carbide inserts at similar cutting conditions with cutting speed ranging from 20-50 m/min, feed rate of 0.25-0.30 mm/rev, and depth-of-cut of 2.0–3.5 mm. The nose wear increased more abruptly compared to flank wear because of increase in the contact length between nose face and work piece at higher cutting speeds, leading to chipping or fracture of nose surface.

Effects of feed rate and depth-of-cut on development of tool wear are presented in Figures 5 and 6, respectively. It can be observed that increase in feed rate and depth-of-cut led to increase in both flank and nose wear. The correlation between feed rate and dept-of-cut, and process parameters such as cutting force, flank and nose wear has been reported by Ezugwu *et al.* [12]. The increase in both flank and nose wear with increase in feed rates and depth-of-cut was attributed to increase in the cutting force and the associated temperature at the cutting edge which led to accelerated wear on the cutting tool.

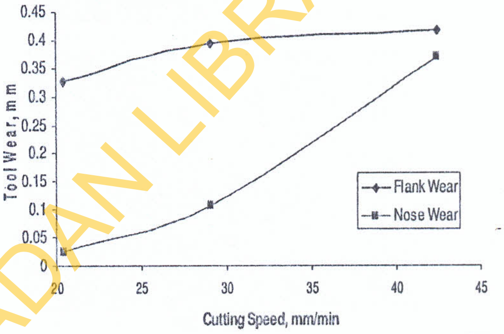


Fig. 4: Effects of cutting speed on tool wear at feed rate of 1.0 mm/rev and depth-of-cut of 0.4 mm.

3.2 Surface roughness

The optical surface roughness of the machined surface against the number of pass for cutting speed of 20.42 mm/s, feed rate of 0.2 mm/rev and depth-of-cut of 1.0 mm is shown in Figure 7. The relationship showed that the surface roughness increased linearly between 0.658 and 0.924 from the 1st pass to the 8th pass. The relationship between the surface roughness and the number of pass was modeled with linear regression equation with a coefficient of determination (R^2-value) equals to 0.986.

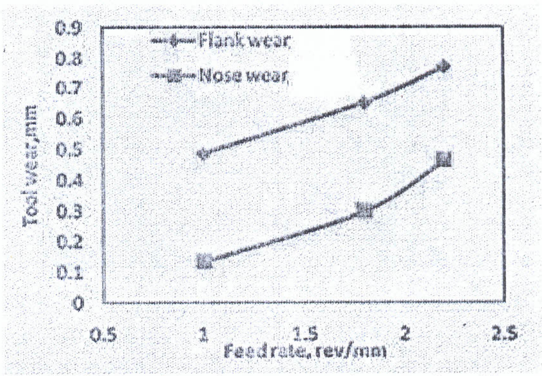


Fig. 5: Effect of feed rate on tool wear at cutting speed of 29.1 m/min and depth-of-cut of 0.8 mm.

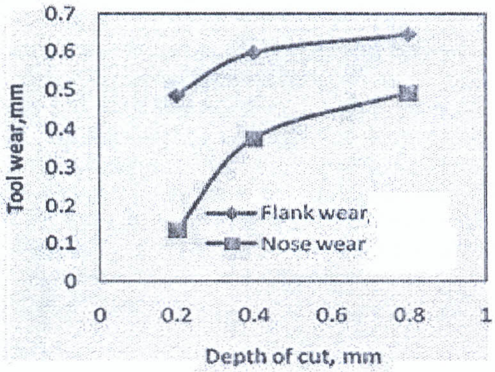


Fig. 6: Effect of depth of cut on tool wear at cutting speed of 29.1 m/min and feed rate of 1.8 mm

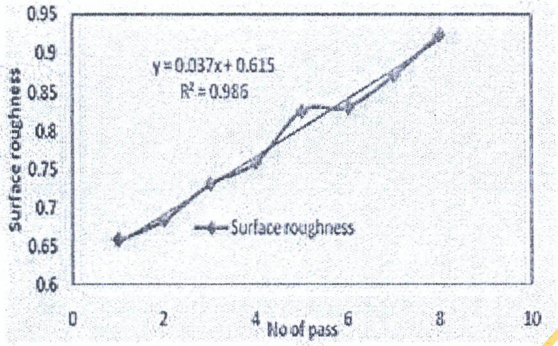


Fig. 7: Optical surface roughness of surfaces machined at different passes with cutting speed of 20.42 mm/s, feed rate of 0.2 mm/rev and depth-of-cut of 1.0 mm

3.3 Chip morphology

Observation of the chip form showed that segmented chips were produced during all the cutting conditions investigated in this study. Generally, the chip form changed from loose arc shape (Figure 8a) to washer type helical shape (Figure 8b) with increase in the number of pass, thus indicating the effect of tool wear on the chip morphology.

Segmented chips with smaller coil radii were produced with increase in depth of cut, while no significant difference was observed with variations in cutting speed and feed rate. Similar observations have been reported by Trent and Wright [13].

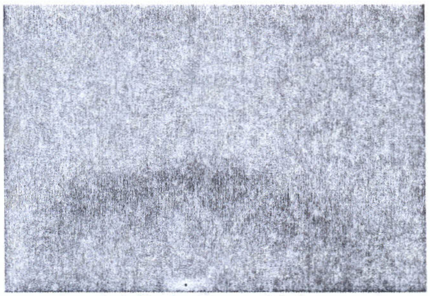
3.4 Microstructure of machined surface

The microstructures of the grains of the workpiece before and after machining operation for the most aggressive cutting condition (cutting speed of 42.4 m/min, feed rate of 1.8 mm/rev, depth-of-cut of 0.8 mm) are shown in Figures 9 (a - b). It can be seen that the microstructure of the surface after machining (Figure 9b) had more black (pearlite) grains than the un-machined surface (Figure 9a). The presence of more pearlite grains impacted more hardness (Case hardening) on the machined surface. The high temperature generated during machining operations has led to recrystalisation of the grains from white (ferrite) grains to black (pearlite) grains.

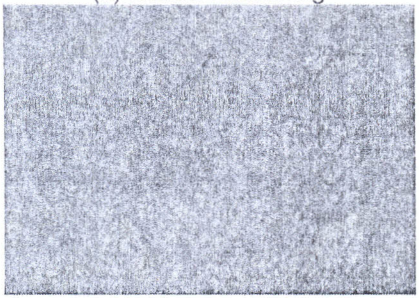
(a) Pass 1

(b) Pass 8

Fig. 8: Chip forms produced at cutting speed of 29.1 mm/s, depth-of-cut of 0.4 mm and feed rate of 1.8 mm/rev.



(a) Before machining



(b) After machining

Fig. 9: Microstructures (x100) of surface before and after machining at cutting speed of 42.4 m/min, feed rate of 1.8 mm/rev, depth-of-cut of 0.8 mm.

3.5 Current consumption

The spindle current is an indicator of the power required during the machining operation. For all cutting speeds considered, current consumed decreased with increase in number of machining pass (cutting length) as depicted in Figure 10. It can be observed that the spindle current also increased with increase in cutting speed (Figure 10). Increase in feed rate and depth of cut also led to increase in spindle current (Figures not shown). Similar observations have been reported by Trent and Wright [13].

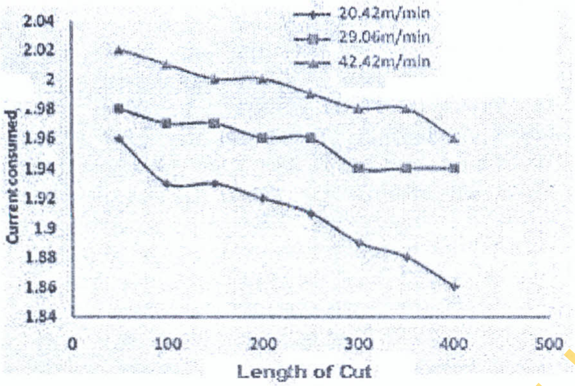


Fig. 10: Spindle current at different cutting speeds with feed rate of 1.8 mm/rev and depth-of-cut of 0.4 mm)

4.0 Conclusions

A performance evaluation of uncoated carbide inserts was determined based on the wear behaviour, surface roughness, chip morphology and microstructure changes in machined surface. For all the cutting conditions investigated, the tool flank wear was greater than nose wear. Surface roughness was found to be dependent on cutting length, cutting speed, depth of cut and feed rate. Segmented chips were produced with smaller coil radii at lower depth of cut. The microstructure of the machined surface revealed a case hardening of the workpiece. The study suggested that the use of uncoated carbide tools tools can enhance the productivity and quality of machining NST 37-2 steel.

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