Arid Zone Journal of Engineering, Technology and Environment, June, 2017; Vol. 13(3):325-335
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Print ISSN: 1596-2490, Electronic ISSN: 2545-5818, www.azojete.com.ng

EXPERIMENTAL EVALUATION OF COATED CARBIDE INSERT ON ALLOY OF STEEL MATERIALS DURING HIGH SPEED TURNING PROCESS

S.A. Lawal[1]*, E.A. Ajani[1], N.O Namessan[2], B.I. Ugheoke[3] and E.A.P. Egbe[1]
[1]*Department of Mechanical Engineering, Federal University of Technology, Minna-Nigeria.*
[2]*Department of Agricultural and Bio-Resources Engineering, Taraba State University, Jalingo- Nigeria*
[3]*Department of Mechanical Engineering, University of Abuja, Nigeria*
*Corresponding author's email: lawalbert2003@yahoo.com

Abstract
The present study investigated the effect of coated carbide turning inserts on the surface roughness of AISI 304L austenitic stainless steel, AISI 316L austenitic stainless steel and AISI 1020 low carbon steel workpiece materials. The three steel grade materials were dry-turned using aluminium oxide (Al_2O_3) duratomic coated inserts at cutting speeds ranging from 1500 – 2000 rpm (229 – 314 m/min), feed rates of 0.25 – 0.75 mm/rev and depth of cut kept constant at 0.5 mm. Surface roughness values at different cutting conditions were measured and analysed. Chips formed at different cutting parameters were collected, classified according to ISO 3685 standards for chip classification and their surface morphology were analysed using optical microscopy. It was observed that feed rate had the greatest influence on surface roughness for the three workpiece materials. Surface finish deteriorated as feed rate increased. The chips formed were generally of the continuous type with built-up-edges.

Keywords: coated inserts; surface roughness; chip-formation; chip morphology

1. Introduction

High speed machining increases metal removal rates, allows for higher productivity, good surface finish and dimensional accuracy in manufacturing processes (Ekinović and Ekinović, 2003). However, as cutting speed increases, cutting temperature, tool wear and machining costs also increase (Abu, 2011; Pathade and Wakchaure, 2013). The use of environmentally friendly cutting fluids keeps cutting temperatures down and prevents environmental and health impacts of conventional cutting fluids (Lawal *et al*., 2007, 2012; Reynolds and Fecher, 2012; Jagdeep and Balwinder, 2014).Dry machining has found several important applications in the production of highly sensitive products such as orthopaedic and surgical implants usually made from hardened steels and hard-to-cut materials such as austenitic stainless steels (Graham *et al.*, 2003; Koepfer, 2003; Fonseca de Silva and Cappa de Oliveira, 2011). Besides dimensional accuracy, surface integrity is the most common requirement of a machined component and this is a tough task when machining hard-to-cut materials. Surface roughness is caused by many machining parameters, such as cutting speed, feed rate, depth of cut, true rake angle and side cutting edge angle, nose radius and machining time. Orrego *et al*., (2010) discovered that the surface finish of AISI 304 stainless steel measured after turning operations was mainly affected by the feed rate. Kaladhar *et al.*, (2011) reported that tool nose radius was the dominant parameter when Physical Vapour Deposition (PVD)coated inserts were used for turning. Suresh *et al.*, (2012) reported that the combination of low feed rate and high cutting speed is necessary for minimizing the surface roughness.

High speed machining of hard-to-cut materials under dry cutting environment leads to the generation of heat and the occurrence of high cutting temperatures at the cutting zone. The development of coated carbide tools has made it possible to dry-cut these materials at high speeds and temperatures producing excellent surface finishes due to the effect of the lubricious coatings which reduces friction and heat generation at the cutting zone (Graham, 2012). Nagalwade and Kale (2014) reported superior performance of TiN coated carbide inserts over uncoated ones during dry-turning of AISI 4140 hardened steel. Kaladhara *et al*., (2012) while turning AISI 304 austenitic stainless steel bars on CNC lathe, under dry cutting environment with duratomic coated cutting inserts at cutting speeds varying from 150 – 210m/min, feed rates of 0.15 – 0.3mm/rev depth of cut of 0.5 – 2.0mm and tool nose radii of 0.4 and 0.8 mm reported that cutting speed was the dominant parameter affecting surface roughness. Optimum cutting conditions for minimum surface roughness were reported at the lowest cutting speed of 150m/min, lowest feed rate of 0.15mm/rev, lowest depth of cut of 0.5mm but at the highest nose radius of 0.8mm. Sharma and Kumar (2014), during the CNC turning of AISI 1018 mild steel with coated carbide insert, at cutting speeds of 60, 80, 100 m/min; feed rate of 0.25, 0.35, 0.45 mm/rev and depth of cut of 0.2,0.3,0.5 mm, reported that surface roughness increases as feed rate increases. Feed rate had the highest influence on surface roughness followed by cutting speed and depth of cut.

Even though high speed turning is greatly desired as it improves productivity, the adverse effects it has on cutting tools, surface finish and chip formation are still being researched. The benefits of dry machining have been enunciated but its effects on cutting temperatures, cutting forces and surface finish of machined parts are adverse. Austenitic stainless steel grades such as AISI 304L and 316L have many important applications but they are very difficult to machine. Aluminium oxide (Al_2O_3) duratomic coated inserts have been claimed to be a ‘wonder’ cutting tool of the future for stainless steel machining but very few research documentation exists on machining with duratomic coated inserts. Very few research documentation exists on the effect of high speed turning of stainless steel workpiece materials, on chip formation, chip morphology and surface roughness. Hence, the aim of the present study was to evaluate the performance of coated carbide inserts during dry turning of three different workpiece materials through the following three objectives: (1) To investigate the effect of coated carbide inserts on the surface roughness of AISI 304L, AISI 316L and AISI 1020 workpiece materials; (2) To study the type of chip formation and (3) To investigate the chip morphology.

2. Materials and Methods

2.1 Workpiece Materials

Three steel grades were used as workpiece materials in this study, namely: (i) AISI 304L austensitic stainless steel, (ii) AISI 316L austenitic stainless steel and (iii) AISI 1020 low carbon steel. In order to confirm their chemical composition, test samples from the three workpiece materials were subjected to spectrometry analysis using Arun Technologies Metal Scan PolySpek Junior Spectrometer. The chemical composition of AISI 304L, AISI 316L and AISI 1020 are presented in Tables 1.

Table 1: Chemical composition of workpiece materials

Material	% C	% Si	% Mn	% Ni	% Cr	% Mo	% P	% S	% Fe
AISI 304L	<1.500	0.483	1.360	7.660	18.560	0	<0.005	0.003	70.960
AISI 316L	<1.500	0.489	1.720	9.530	16.920	1.740	<0.005	0.004	68.850
AISI 1020	0.177	0.233	0.558	0	0	0	0.035	0.017	98.430

2.2 Cutting Tool Material

The newly introduced Al_2O_3duratomic coated insert number CNMG160616-MR7,TM4000 sourced from Seco Tools AB, Fagersta, Sweden was the cutting tool used in this research. Duratomic (coined from two words; ‘Durable’ and ‘atomic’), is an α-based Al_2O_3 coating which involves an arrangement of the aluminium and oxygen atoms in a unique way to improve the mechanical properties as well as the thermal and chemical inertness of the insert.

2.3 Turning Operation

The experimental design was based on One Variable at a Time (OVAT) method. A total of 15 experimental runs were conducted on each of the three workpiece materials as shown in Table 2. Three cutting parameters namely cutting speed, feed rate and depth of cut were considered. The cutting speed was varied from1500–2000 rpm; feed rate was varied from 0.25 – 0.75mm/rev while depth of cut was fixed at 0.5 mm.

Table 2: Experimental design for the turning operation

Experimental Run No.	Cutting Speed (rpm)	Feed Rate (mm/rev)	Depth of Cut (mm)
1	1500	0.25	0.5
2	1625	0.25	0.5
3	1750	0.25	0.5
4	1875	0.25	0.5
5	2000	0.25	0.5
6	1500	0.50	0.5
7	1625	0.50	0.5
8	1750	0.50	0.5
9	1875	0.50	0.5
10	2000	0.50	0.5
11	1500	0.75	0.5
12	1625	0.75	0.5
13	1750	0.75	0.5
14	1875	0.75	0.5
15	2000	0.75	0.5

The values of these cutting parameters were selected based on the configuration of the Kovosvit MAS SPT-32 CNC slant-bed turning centre used for the turning operation. The experimental set up for the turning operation is as shown in Figure 1. It is equipped with a 6 station turret. It operates on a FANUC 0i-Mate-TD control system with a maximum cutting speed capacity of 4000 rpm, maximum feed rate of 15 m/min, maximum length between centres of 1500 mm, maximum workpiece diameter of 490 mm and maximum workpiece weight of 300 kg. The cutting tool (coated carbide insert) with part number TNMG160616-MR7, TM4000 was mounted on a right handed PCLNR3232P16 – G2KVOO tool holder, fastened on the 6-station turret, was used for the turning operations. For each of the steel materials, the workpieces to be mounted on the lathe were cut to sizes 50 mm diameter by 250 mm length dimension and machined to a length of 100 mm.

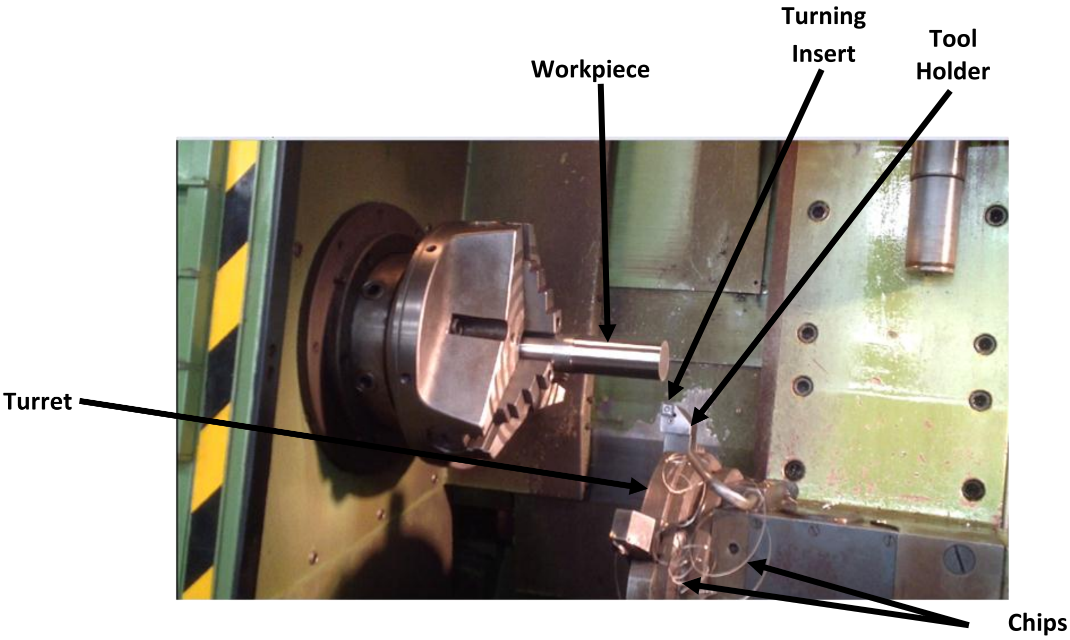


Figure 1: Experimental set up for turning operation

2.4 Surface Roughness Measurement

After each turning operation, the surface roughness of the machined surface was measured using the SRT-6210S Surface Roughness Tester having a diamond stylus tip of radius 5µm. The experimental set up for surface roughness measurement is presented in Figure 2. A cut-off length (or sampling length) of 0.8mm was used for surface roughness measurements between 0.36 and 2.5µm while 2.5mm cut-off length was used for surface roughness measurements above 2.5µm. The average roughness (R_a) was measured at three positions along the machined surface, that is, at the middle and at 10mm from the two ends of the machined surface. The average of the three R_a values measured was calculated and recorded for each experimental run.

Figure 2: Experimental set up for surface roughness measurement

2.5 Chip Formation

After the completion of each experimental run, sample of the chips formed were collected and labelled. The surface morphology of the samples of chips formed during each of the experimental runs was investigated at 100x magnification under the Nikon Eclipse – ME600 optical metallurgical microscope.

3. Results and Discussion

3.1 Surface roughness

Figures 3 and 4 compared the plots of surface roughness values against feed rate for the three workpiece materials at a cutting speed of 1500 and 2000 rpm respectively. Surface roughness values increased as feed rate increased at about the same rate for the three workpiece materials.

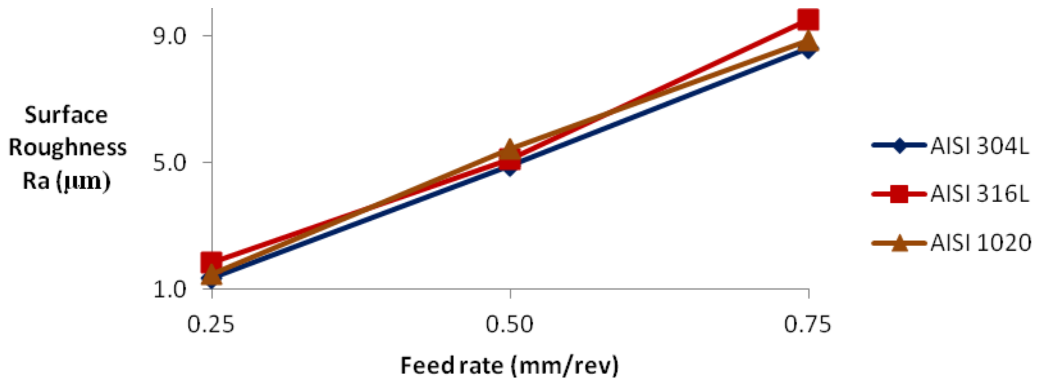


Figure 3: Surface roughness against feed rate at 1500 rpm cutting speed

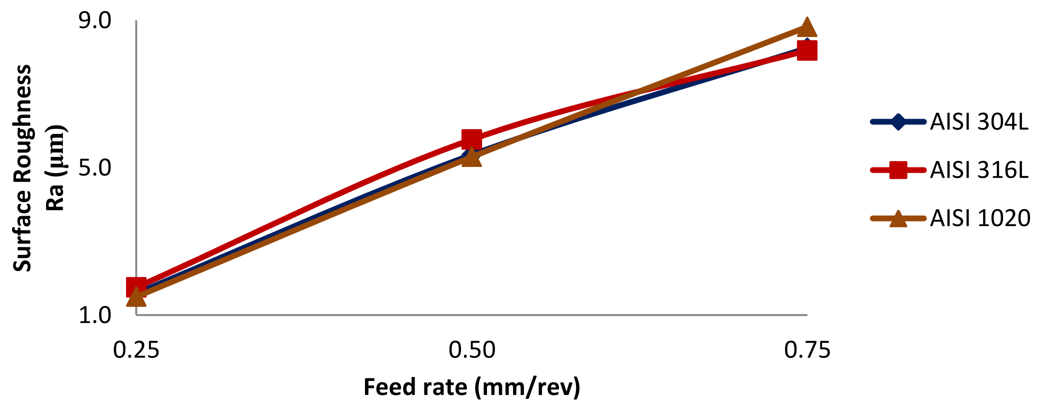


Figure 4: Surface roughness against feed rate at 2000 rpm cutting speed

Figure 5 shows the plot of surface roughness values against feed rate for AISI 304L austenitic stainless steel workpiece material at different cutting speeds. At each of the cutting speeds, surface roughness values increased at a similar rate as feed rate increased. The influence of increase in feed rate on surface roughness is more significant, whereas changes in cutting speeds had not significant influence on surface roughness. Similar observations were made for AISI 316L and AISI 1020 steel workpiece materials as shown in Figures 6 and 7. This result correlates with the observation reported by Nagalwade and Kale (2014) while dry turning AISI 4140 hardened steel with TiN coated carbide inserts at cutting speeds of 100 - 130 m/min, feed rates ranging from 0.1 – 0.3 mm/rev and depth of cut of 0.2 - 0.5 mm. They reported that surface finish deteriorated as feed rate increased and that feed rate had the greatest influence on surface roughness, followed by cutting speed and least by the depth of cut.

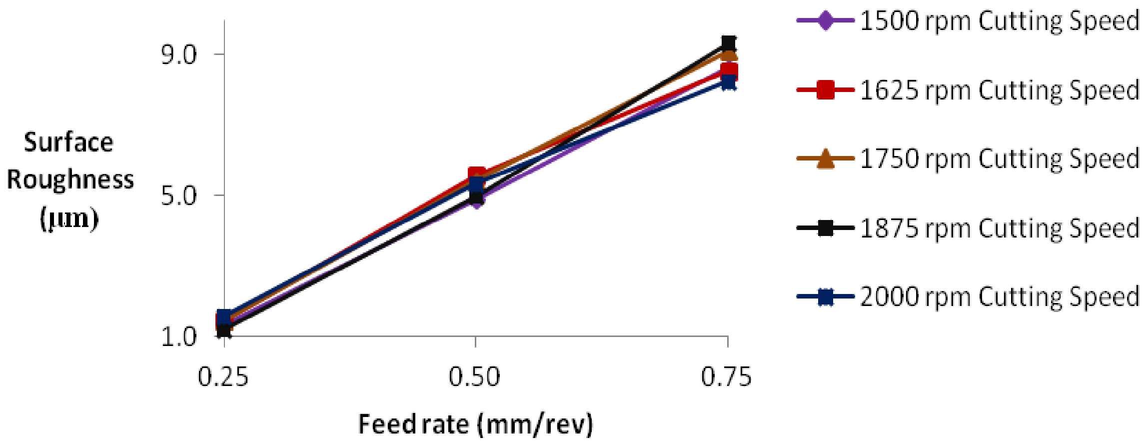


Figure 5: Surface roughness against feed rate for AISI 304L

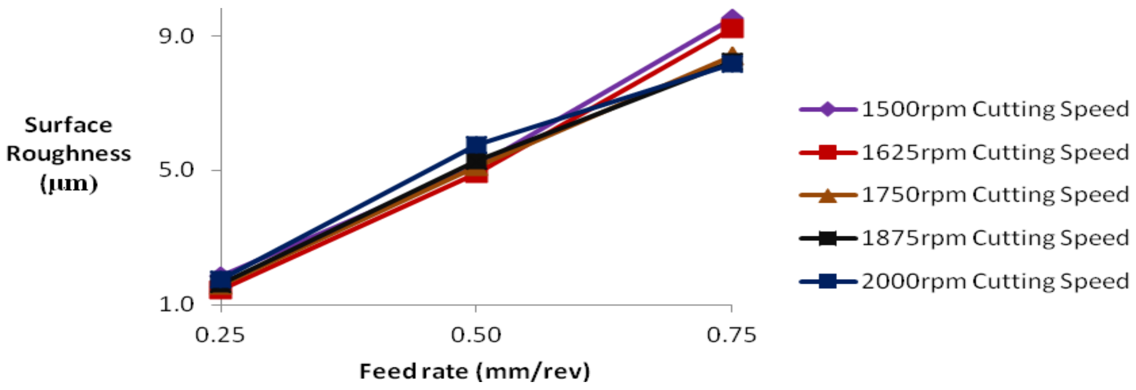


Figure 6: Surface roughness against feed rate for AISI 316L

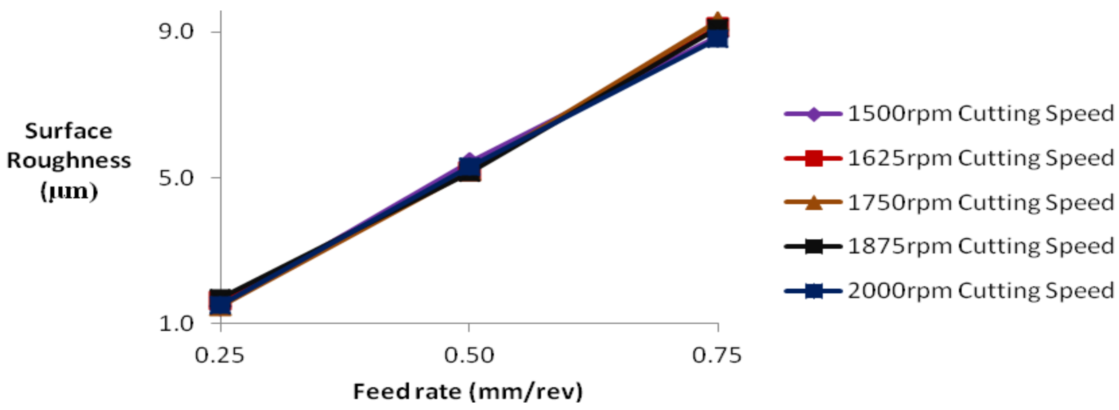


Figure 7: Surface roughness against feed rate for AISI 1020

3.2 Chip Formation

Type of chip formation for the three workpiece materials is presented in Table 3 (a & b). The chips are compared and categorized according to ISO 3685 standards for chips classification. The nature of chips formed was majorly continuous chips of different forms. This is similar to the observation of Ramana *et al.*, (2014). For AISI 304L austenitic stainless steel workpiece material, snarled ribbon chip was the most prevalent chip type followed by long ribbon chips form and finally long washer-type helical chip. For AISI 316L austenitic stainless steel workpiece material, the types of chip formation observed are the washer-type helical chips, ribbon chips and the arc chips. For AISI 1020 low carbon steel workpiece material, washer-type helical chips and ribbon chips were observed.

Table 3a: Types of chips formed for the three workpiece materials

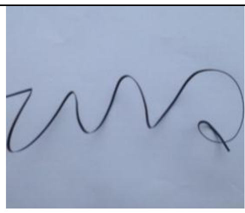
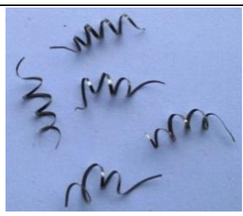
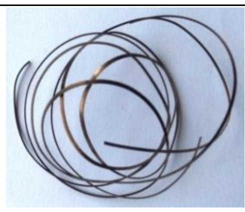
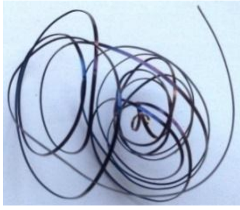
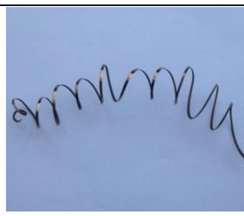
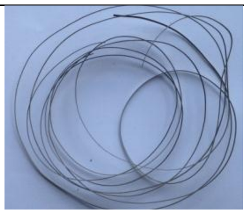
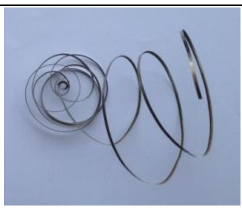
Cutting Parameter	**Workpiece Material**		
	AISI 304L	**AISI 316L**	**AISI 1020**
V_c - 1500 rpm f - 0.25 mm/rev DoC - 0.5 mm	 **Snarled Ribbon Chip**	 **Long Washer-type Helical Chip**	 **Snarled Ribbon Chip**
V_c - 1750 rpm f - 0.25 mm/rev DoC - 0.5 mm	 **Snarled Ribbon Chip**	 **Short Washer-type Helical Chip**	 **Long Washer-type Helical Chip**
V_c - 2000 rpm f - 0.25 mm/rev DoC - 0.5 mm	 **Snarled Ribbon Chip**	 **Snarled Ribbon Chip**	 **Snarled Ribbon Chip**
V_c - 1500 rpm f - 0.5 mm/rev DoC - 0.5 mm	 **Long Washer-type Helical Chip**	 **Long Ribbon Chip**	 **Long Ribbon Chip**

Table 3b: Types of chips formed for the three workpiece materials

Cutting Parameter	**Workpiece Material**		
	AISI 304L	**AISI 316L**	**AISI 1020**
V_c - 1750 rpm f - 0.5 mm/rev DoC - 0.5 mm	 **Snarled Ribbon Chip**	 **Snarled Ribbon Chip**	 **Snarled Ribbon Chip**
V_c - 2000 rpm f - 0.5 mm/rev DoC - 0.5 mm	 **Long Ribbon Chip**	 **Long Ribbon Chip**	 **Snarled Ribbon Chip**
V_c - 1500 rpm f - 0.75 mm/rev DoC - 0.5 mm	 **Snarled Ribbon Chip**	 **Snarled Washer-type Helical Chip**	 **Long Washer-type Helical Chip**
V_c - 1750 rpm f - 0.75 mm/rev DoC - 0.5 mm	 **Long Ribbon Chip**	 **Long Ribbon Chip**	 **Snarled Ribbon Chip**
V_c - 2000 rpm f - 0.75 mm/rev DoC - 0.5 mm	 **Snarled Ribbon Chip**	 **Snarled Ribbon Chip**	 **Snarled Ribbon Chip**

The surface morphology of chip formed during the machining of AISI 304L austenitic stainless steel at a cutting speed of 2000 rpm, feed rate of 0.75 mm/rev and depth of cut of 0.5 mm is shown in Figure 8. Deposits of Built-Up-Edge (BUE) were observed on the chips. Similar images for AISI 316L and AISI 1020 presented in Figures 9 and 10 respectively also show the occurrence of BUE deposits on the chips formed.

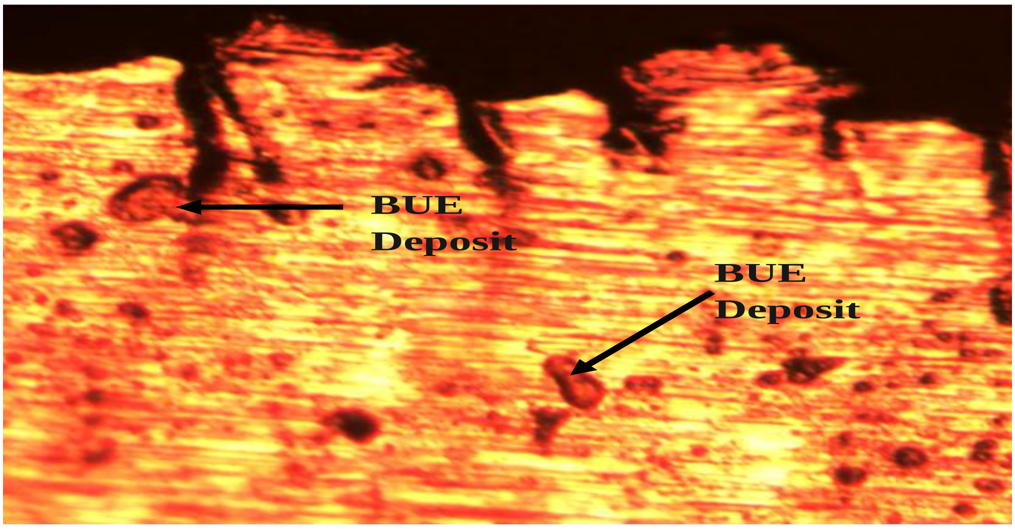


Figure 8: Micrograph of chips formed from AISI 304L at 2000 rpm cutting speed, 0.75 mm/rev feed rate and 0.5 mm depth of cut, at magnification – 100X

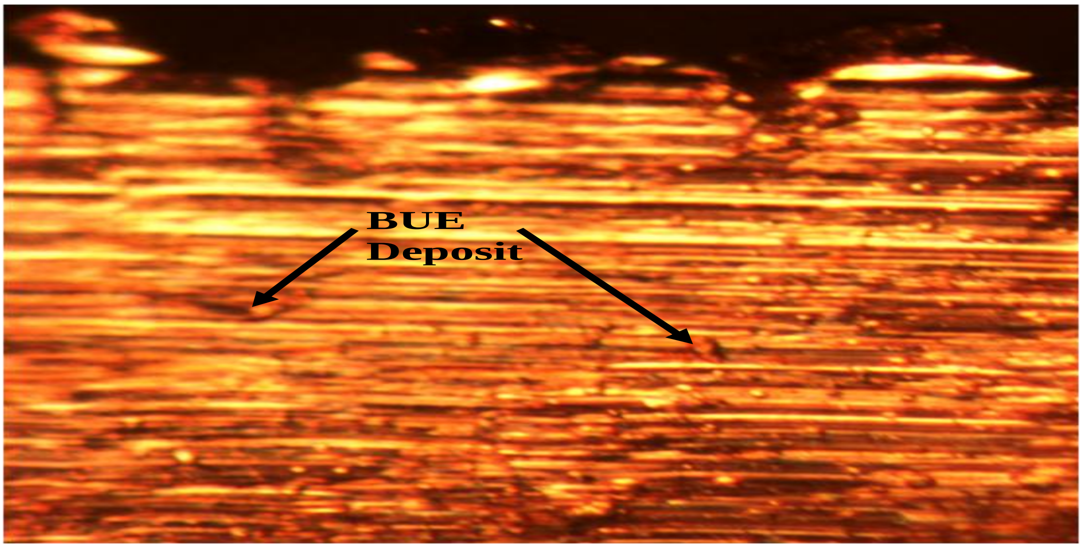


Figure 9: Micrograph of chips formed from AISI 316L at 2000 rpm cutting speed, 0.75 mm/rev, feed rate and 0.5 mm depth of cut, at magnification – 100X

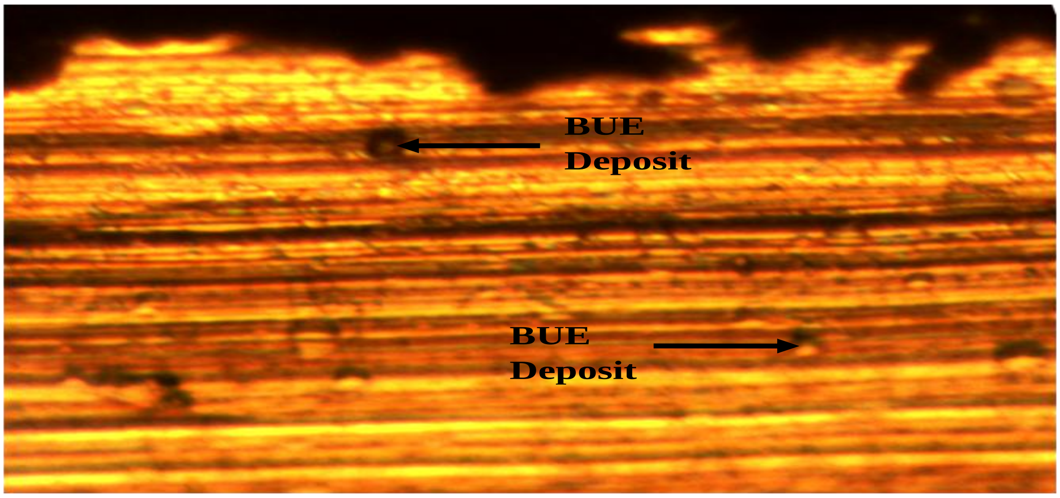


Figure 10: Micrograph of chips formed from AISI 1020 at 2000 rpm cutting speed, 0.75 mm/rev feed rate and 0.5 mm depth of cut, at magnification – 100X

4. Conclusions

In the present study, three workpiece materials AISI 304L, AISI 316L and AISI 1020 were dry-turned with aluminium oxide (Al_2O_3) duratomic coated inserts number CNMG160616-MR7, TM4000 at cutting speeds ranging from 1500 – 2000 rpm (229 – 314 m/min), feed rates 0.25 – 0.75 mm/rev and depth of cut kept constant at 0.5 mm. The following are the conclusions:

i. Feed rate had the greatest influence on surface roughness for the three workpiece materials, it was observed that, as feed rate increased, surface roughness also increased.
ii. The chips formed were generally of the continuous type with built-up-edge.
iii. It was observed that, snarled ribbon chip was the most prevalent chip type, followed by long ribbon chips form and long washer-type helical chip for AISI 304L austenitic stainless steel workpiece material; for AISI 316L austenitic stainless steel workpiece material, the types of chip formation observed were the washer-type helical chips, ribbon chips and the arc chips and for AISI 1020 low carbon steel workpiece material, washer-type helical chips and ribbon chips were the two types of chips observed.

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