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Experimental study on the effect of electric current applied at the interface of cutting tool and workpiece for turning operation

Akhil Soman*, Anbarasan N., Hareesh P., Kuppan P.

School of Mechanical and Building Sciences, VIT University, Vellore - 632014, Tamil Nadu, India.

Abstract

The wear of a cutting tool determines its life. Lesser the wear, more is the life of cutting tool and consequently the tool has to be replaced less frequently. This results in an increase in productivity of the machining operation, reduces manufacturing lead time and lowers the cost of production. Optimization of the process, use of cutting fluids for lubrication and hard coatings on the tool are the widely used methods to reduce tool wear. It has been recorded in previous studies that application of electric current to moving surfaces in contact, influences the wear of both the surfaces. The wear rate of the anodic surface was reduced and that of cathodic surface was increased. This paper attempts to study the effects of application of DC electric current on wear of turning insert during the turning operation of stainless steel 304 material. In the first phase of study, an L_{18} orthogonal array experiment was designed to study the effects of various factors (use of cutting fluid, polarity of cutting tool, applied voltage, cutting speed, feed and depth of cut) on insert wear and surface roughness of stainless steel 304 rod post machining. In the second phase of the experiment, the insert wear at different polarities were recorded at regular intervals of 70 mm cutting length while keeping the cutting parameters constant. Each cut was carried out for a total of 560 mm. The recorded readings are compared.

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Keywords: Tool wear; Dry turning; Electric current; Oxide layer.

1. Introduction

Wear is the removal of material caused due to friction between two surfaces in sliding contact. Two types of tool wear are observed in orthogonal metal cutting; namely flank wear and crater wear. Flank wear is caused due to

* Corresponding author. Tel.: +91 9769199452.
E-mail address: akhil.soman2013@vit.ac.in

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friction between the tool and finished part of the workpiece. Crater wear occurs due to sliding of chips on the rake face of the tool. Tool wear may cause increase in cutting forces, increase in temperatures, and reduction in dimensional accuracy of finished part. In some cases the tool may break because of weakening. Thus it is imperative that tool wear should be minimized as much as possible. Traditionally coatings to increase surface hardness, lubricating oil and coolants have been used as an effective medium to reduce wear and increase tool life.

It has been observed in previous investigations that for a pairing of dissimilar metals, wear rates of both surfaces can be influenced by application of electrical potential [1]. The wear of the two surfaces are also influenced by the additives in the lubricant as each additive responds differently to current. Friction and wear between surfaces of dissimilar metals can be influenced by application of direct current voltage across the two surfaces [2]. The polarities of contacting surfaces have notable effect on friction forces during mating of joints. Electromotive forces like magnetic field generated through DC or AC sources have also been found to improve tool life [3]. In an investigation conducted by Gangopadhyay et al. [4], it was observed through a ball and disk test, in presence of conventional lubricant used in metal cutting, that wear of anode surfaces decreased and that of cathode surfaces increased compared to condition where no current was passed. DC voltage was used in this case. This concept was applied to study wear characteristics of milling inserts for face milling operation. The results of the above test showed that the insert wear and vibrations reduced notably when the insert was anode. Also the wear and vibrations of the insert had increased when the insert was cathode.

The above results are fascinating and are capable of creating significant impact in the metal cutting industry. Reduction in tool wear will have a positive effect on productivity of various machine tools. Cost of operating the machine tool will also be reduced due to less frequent replacement of cutting tool. The effect of electric current on wear needs to be explored more and should be applied in conjunction with the other widely used methods of wear reduction to further enhance tool life. This study was conducted to investigate whether effects similar to those observed during the face milling test can be reproduced for turning operation using uncoated inserts.

Stainless steel is one of the most widely used ferrous materials due to its unique corrosion resistance property. Austenitic stainless steel AISI grade 304 is also known as the 18/8 stainless steel due to composition consisting of 18% and 8% by wt. chromium and nickel respectively. It is the most common variant of stainless steel. This paper concentrates on the machining of stainless steel 304 using a novel method of metal cutting.

2. Test Procedure

Turning operation of stainless steel 304 (30 HRC hardness) material with THM-F CNMA120408 turning insert (Fig. 1) was done. The machine tool utilized was Esteam ETM 510x1500 heavy duty lathe. DC supply with maximum 25V output capacity was used. The electrical circuit was connected as shown in Fig. 2. It is necessary that the inset holder is insulated from the tool post so that electric current would pass only through the tool and workpiece contact and not through the machine. The lubricant used for these tests was emulsion of 10% metal cutting oil and 90% water.

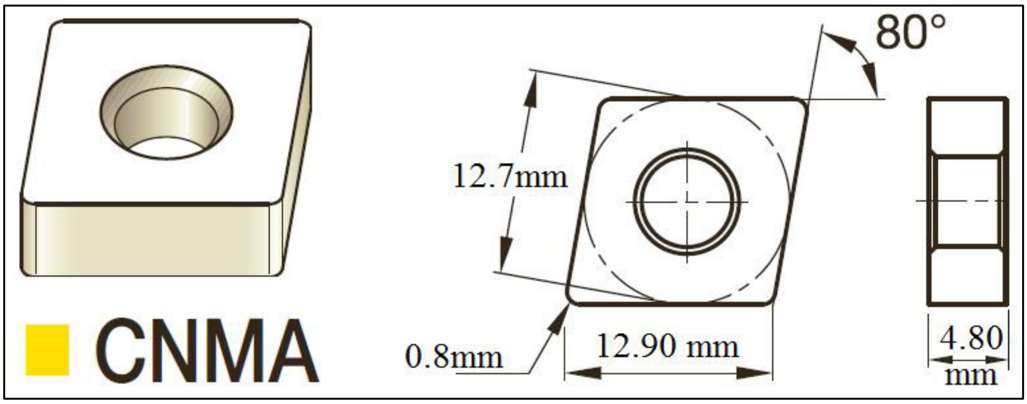

Fig. 1. Geometry of CNMA120408 turning insert.

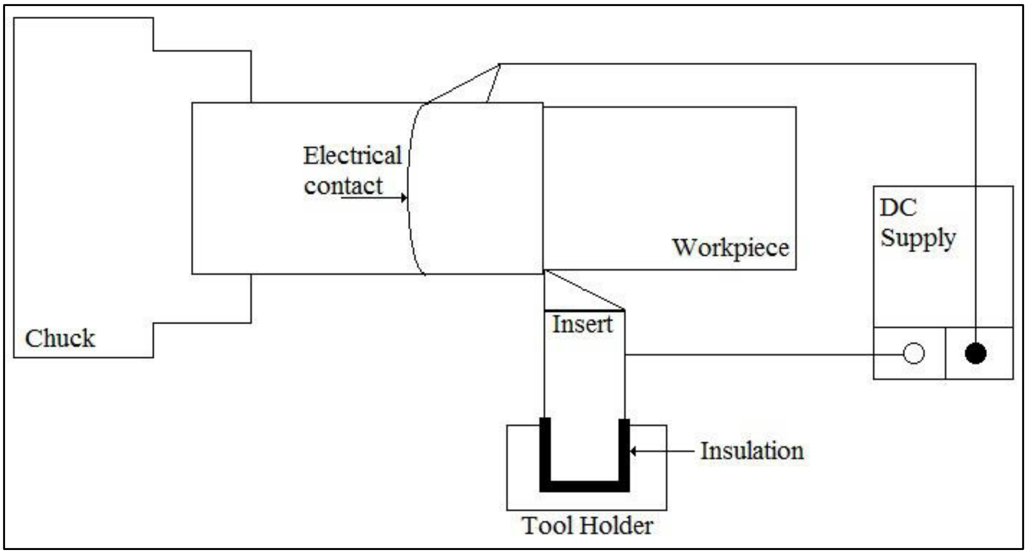

Fig. 2. Experimental setup showing electrical circuit.

Table 1. Chemical composition of stainless steel 304 (wt. %).

C	Cr	Ni	Mn	P	S	Si	Fe
< 0.08	18	8	< 2	< 0.045	< 0.03	< 0.75	balance

2.1 Phase 1

Turning operation was performed by varying the factors according to L_{18} orthogonal array designed in MINITAB^{TM} 16 software as shown in Table 2. Factors which may influence the cutting operation like use of cutting fluid, polarity of cutting tool, applied voltage, cutting speed, feed and depth of cut were considered. Each cut was done over a fixed length of 250 mm.

Insert flank wear was recorded using Carl Zeiss Metallurgical microscope-Axios Kop 40 MAT interfaced by CL 15 - 203 Clemex Vision PE software. Surface roughness values R_a and R_t were recorded using TalySurf profilometer interfaced with MarWin software.

Table 2. L_{18} orthogonal array.

S.No.	Cutting Oil	Voltage (V)	Polarity	Cutting Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)
1	Dry	10	Neutral	50	0.15	0.4
2	Dry	10	Negative	100	0.2	0.7
3	Dry	10	Positive	150	0.1	1
4	Dry	15	Neutral	50	0.2	0.7
5	Dry	15	Negative	100	0.1	1
6	Dry	15	Positive	150	0.15	0.4
7	Dry	20	Neutral	100	0.15	1
8	Dry	20	Negative	150	0.2	0.4
9	Dry	20	Positive	50	0.1	0.7
10	Wet	10	Neutral	150	0.1	0.7
11	Wet	10	Negative	50	0.15	1
12	Wet	10	Positive	100	0.2	0.4
13	Wet	15	Neutral	100	0.1	0.4
14	Wet	15	Negative	150	0.15	0.7
15	Wet	15	Positive	50	0.2	1
16	Wet	20	Neutral	150	0.2	1
17	Wet	20	Negative	50	0.1	0.4
18	Wet	20	Positive	100	0.15	0.7

2.2 Phase 2

Dry machining of stainless steel 304 was done. A constant cutting speed of 70 m/min and 0.3 mm depth of cut was used for the tests. Automatic feed rate of 0.103 mm/rev had been maintained. DC voltage of 15V was applied.

Flank wear was measured using Tesa-Visio 300 DCC optical coordinate measuring machine interfaced with PC-DMIS Vision software. The optical CMM has an X,Y,Z Encoder resolution of 0.05 µm. Insert flank wear was recorded for 560 mm cutting length at intervals of 70 mm.

Three tests were conducted:
(1) Tool wear measurement without application of electric current.
(2) Tool wear measurement with application of electric current by keeping tool as cathode.
(3) Tool wear measurement with application of electric current by keeping tool as anode.

3. Observations

3.1 Phase 1

The values of flank wear and surface roughness were recorded as shown in Table 3. The results of the L_{18} orthogonal array experiments were analyzed using MINITAB^{TM} 16 software.

Analysis for flank wear and surface roughness of the work material post machining were done separately. Response table for means and main effects plot for means were generated to study effects of the various factors.

Table 3. Recorded values of flank wear ($V_b$max) and surface roughness (R_a, R_t).

S.No.	Cutting Oil	Voltage (V)	Polarity	Cutting Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	R_a (µm)	R_t (µm)	R_t/R_a	$V_b$max (µm)
1	Dry	10	Neutral	50	0.15	0.4	0.7791	3.8179	4.900398	130
2	Dry	10	Negative	100	0.2	0.7	1.333733	8.5357	6.399857	1154
3	Dry	10	Positive	150	0.1	1	0.949	9.3476	9.849947	433
4	Dry	15	Neutral	50	0.2	0.7	0.7628	8.2859	10.86248	188
5	Dry	15	Negative	100	0.1	1	1.0202	9.663	9.471672	280
6	Dry	15	Positive	150	0.15	0.4	0.889833	6.6929	7.521524	345
7	Dry	20	Neutral	100	0.15	1	1.5625	8.6461	5.533504	1010
8	Dry	20	Negative	150	0.2	0.4	0.9145	5.678833	6.209768	1229
9	Dry	20	Positive	50	0.1	0.7	0.7676	6.6704	8.689943	449
10	Wet	10	Neutral	150	0.1	0.7	1.6319	15.4517	9.468534	973
11	Wet	10	Negative	50	0.15	1	1.216	8.1401	6.694161	614
12	Wet	10	Positive	100	0.2	0.4	1.1418	12.9999	11.38544	518
13	Wet	15	Neutral	100	0.1	0.4	0.8501	6.1089	7.186096	497
14	Wet	15	Negative	150	0.15	0.7	1.111833	9.6842	8.710121	574
15	Wet	15	Positive	50	0.2	1	1.443633	9.0558	6.272924	615
16	Wet	20	Neutral	150	0.2	1	1.074667	6.2465	5.812498	656
17	Wet	20	Negative	50	0.1	0.4	1.0639	8.2018	7.709183	427
18	Wet	20	Positive	100	0.15	0.7	1.238233	7.6642	6.189627	692

Table 4. Response Table for Means ($V_b$max).

Level	Cutting oil	Voltage (V)	Polarity	Cutting Speed (mm/min)	Feed (mm/rev)	Depth of cut (mm)
1	579.8	637.0	713.0	403.8	509.8	524.3
2	618.4	416.5	575.7	691.8	560.8	671.7
3		743.8	508.7	701.7	726.7	601.3
Delta	38.7	327.3	204.3	297.8	216.8	147.3
Rank	6	1	4	2	3	5

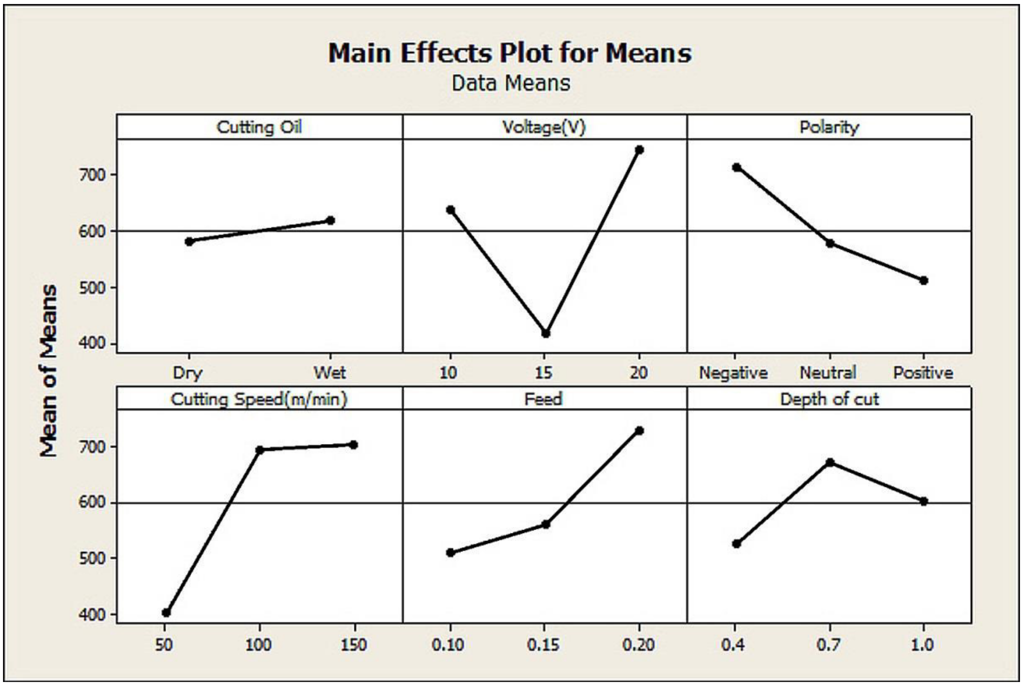

Fig. 3. Effect of process parameters for average Mean for $V_b$max.

The response table for means (Table 4) shows that the factor affecting insert flank wear most is voltage. The main effects plot for means (Fig. 3) shows that minimum insert wear will be observed for the following conditions:

- Dry cutting
- 15 V voltage
- Positive polarity of insert
- 50 m/min cutting speed
- 0.1 mm/rev feed rate
- 0.4 mm depth of cut

We may observe from the result analysis that the polarity of the cutting tool has influenced the insert wear. The wear is shown to have been reduced with tool as anode compared to neutral cutting. The tool wear increased when the tool was at negative polarity. Another thing to be noticed is that the use of lubricating fluid with the application of current has increased tool wear. These effects have been discussed in detail later in this paper.

Table 5. Response Table for Means (R_a).

Level	Cutting oil	Voltage (V)	Polarity	Cutting Speed (mm/min)	Feed (mm/rev)	Depth of cut (mm)
1	0.9977	1.1753	1.1100	1.0055	1.0471	0.9399
2	1.1969	1.0131	1.1102	1.1911	1.1329	1.1410
3		1.1036	1.0717	1.0953	1.1119	1.2110
Delta	0.1992	0.1622	0.0385	0.1856	0.0858	0.2711
Rank	2	4	6	3	5	1

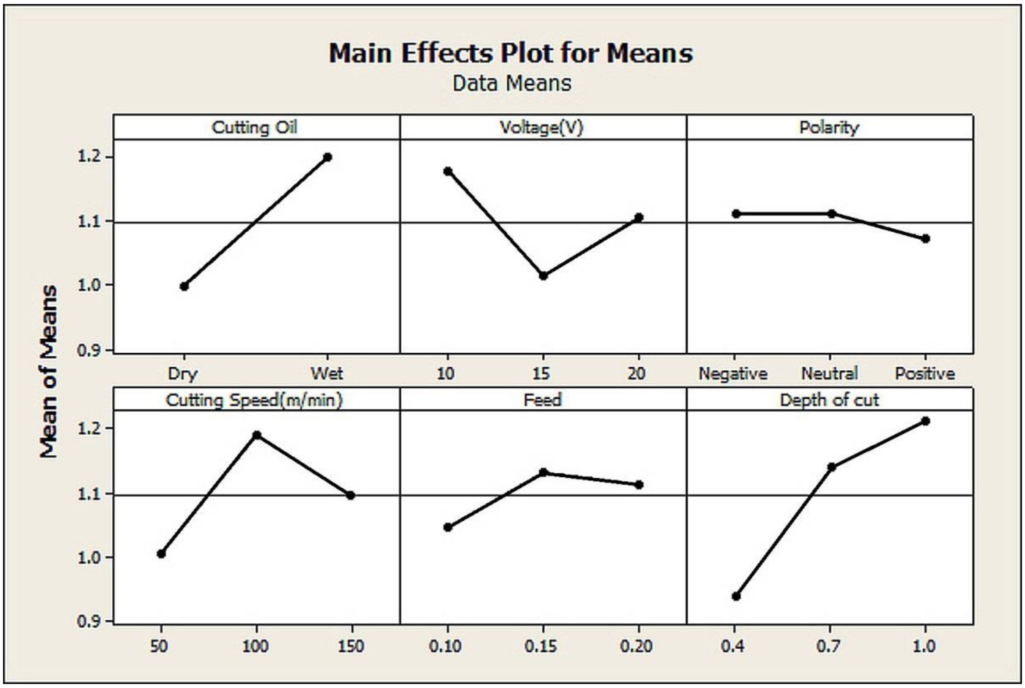

Fig. 4. Effect of process parameters for average Mean value for R_a.

The response table for means (Table 5) shows that the factor affecting surface roughness the most was depth of cut. The main effects plot for means (Fig. 4) shows that minimum surface roughness will be observed for the following conditions:

- Dry cutting
- 15 V voltage
- Positive polarity of insert
- 50 m/min cutting speed
- 0.1 mm/rev feed rate
- 0.4 mm depth of cut

Material removal was better with tool as anode and the machining was also relatively smoother compared to normal cutting conditions. Similar to the previous analysis of flank wear, it is observed that lubricating oil should not be used along with application of electric current. Use of lubricating oil with application of electric current increases both tool wear and surface roughness.

3.2 Phase 2

The insert flank wear values which recorded at intervals of 70 mm over total cutting length of 560 mm are compared in the graph shown in Fig. 4. Optical CMM images of the flank wear are also compared for 280 mm (Fig. 3), 420 mm (Fig. 5) and 560 mm (Fig. 7) of cutting for the three cases. The height of the rectangle gauge gives wear length.

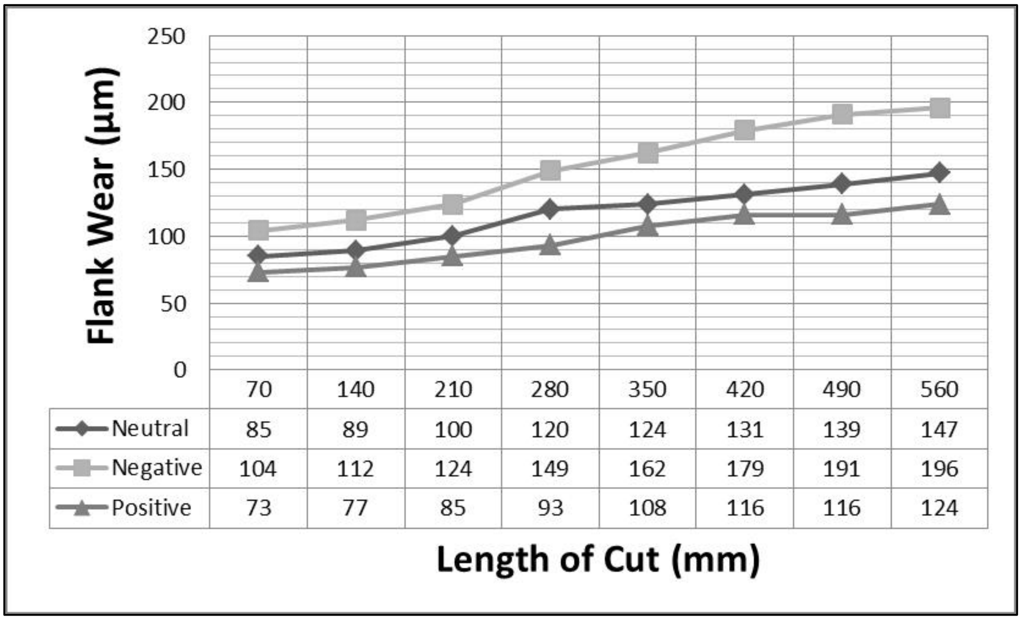

Fig. 5. Comparison of insert flank wear for different polarities of the insert.

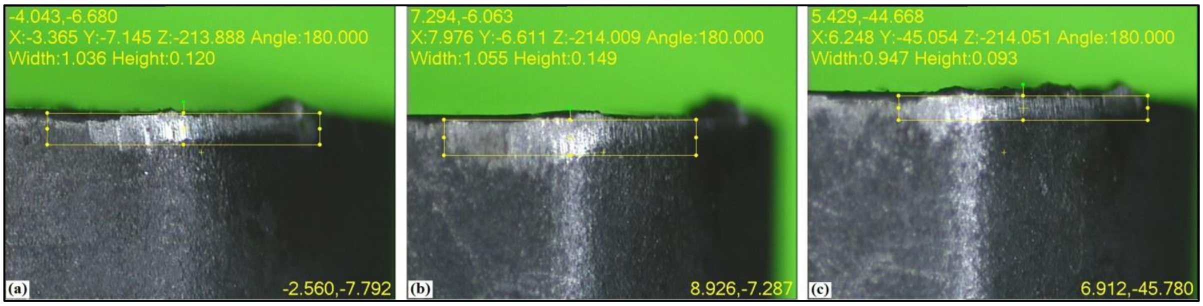

Fig. 6. Optical CMM images showing insert flank wear for 280mm of cutting (4.4x Optical magnification). (a) Neutral; (b) Negative; (c) Positive.

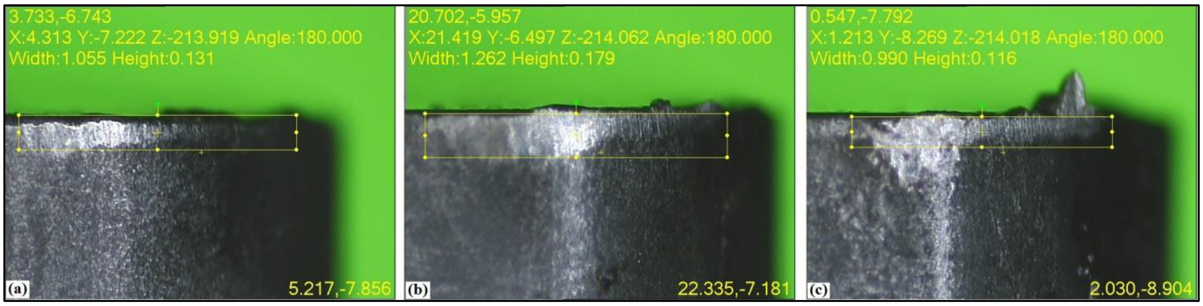

Fig. 7. Optical CMM images showing insert flank wear for 420mm of cutting (4.4x Optical magnification). (a) Neutral; (b) Negative; (c) Positive.

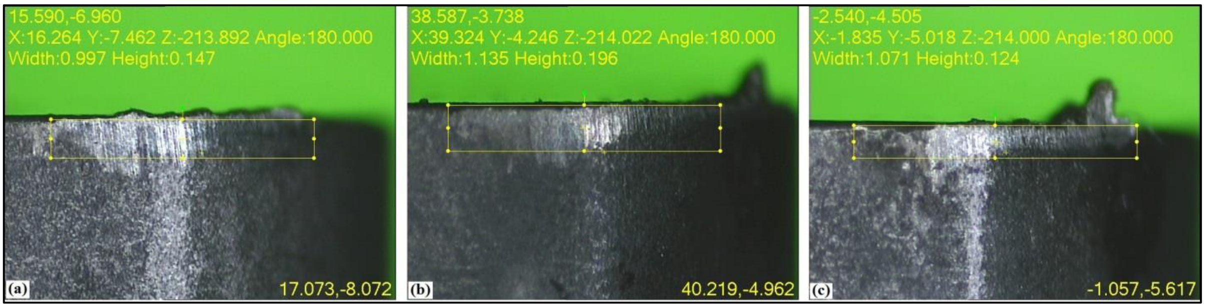

Fig. 8. Optical CMM images showing insert flank wear for 560mm of cutting (4.4x Optical magnification). (a) Neutral; (b) Negative; (c) Positive.

4. Discussions

The results show that wear of the insert had been influenced by the application of direct current. Compared to normal cutting conditions the wear of the insert had increased when it was given negative polarity. On the other hand the wear of the insert had decreased when it was given positive polarity. Improvement in the machining of the raw material was also observed when the cutting tool was anode.

The change in wear can be attributed to the formation of protective oxide film [5]. The surface film elemental composition is changed which results in different wear rates for cathode and anode surfaces. Tribological action generates oxide debris that compact against one or both sliding surfaces which sinter together at high temperatures (ranging from ambient to 800°C) to form a 'glaze' layer. This mechanically resistant layer prevents direct contact between the two sliding surfaces reducing adhesion wear [6, 7]. Formation of the oxide film depends on the electrical polarity of the surface. Cathodic surfaces show more wear as the development of protective film is suppressed due to the direction of applied electric potential. Anodic surface develops a thicker film of oxide due to favorable corrosion potential. This results in reduction of wear between the contacting surfaces occurring due to adhesion. The oxide film should be stable and should not break during the course of cutting. An EDS analysis confirmed the presence of oxides at the rake face close to cutting edge (Fig. 9) for insert used for cutting with positive polarity.

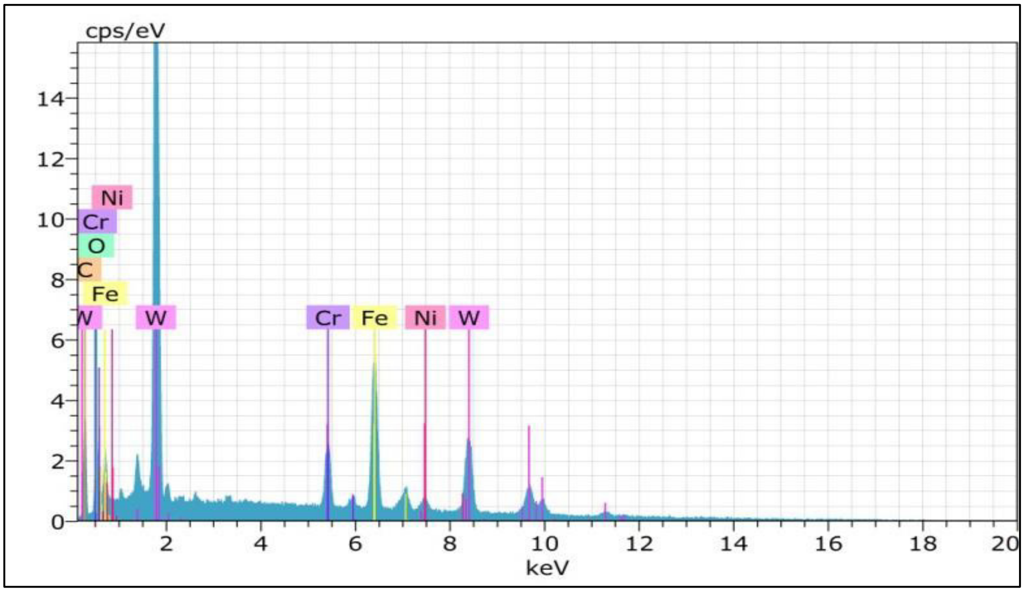

Fig. 9. EDS spectrum taken at rake surface showing presence of oxygen element.

Table 6. Elemental composition of rake surface near cutting edge using EDS analysis.

EL	AN	Series	unn. C [wt. %]	norm. C [wt. %]	Atom. C [at. %]	Error (1 Sigma) [wt. %]
W	74	L-series	53.73	50.62	10.63	1.79
Fe	26	K-series	19.20	18.09	12.51	0.63
C	6	K-series	17.95	16.91	54.35	4.19
O	8	K-series	7.63	7.19	17.35	1.98
Cr	24	K-series	5.32	5.01	3.72	0.23
Ni	28	K-series	2.31	2.18	1.43	0.16
		Total:	106.14	100.00	100.00	

Flooding the workpiece tool interface with water soluble lubricating oil prevents the formation of oxide layer and increases tendency for both the surfaces to wear by corrosive action in presence of electric field. The corrosion resistance property of stainless steel is also decreased in non-oxygenated environment. Hence it is advisable to use the application of electric current only during dry turning. Lubricating oil of different chemical compositions should be tried and tested for their use in conjunction with DC application to further reduce tool wear and improve surface finish of the workpiece.

The intensity of electric current passing through the areas in contact is of importance. Increase in electric current will cause increase in temperature on both surfaces due to Joule heating. As a result the wear of both the workpiece surface and insert will increase. Hardness of the tool will also reduce at higher temperatures during machining which is not favorable. This phenomenon needs to be considered and thus values of electric current should be kept low. Use of coolants that would not interfere with the formation of protective oxide layer is suggested for reducing the temperature of the cutting tool.

5. Conclusions

The application of direct current to the turning operation has significantly changed the wear characteristics of the tool and from the investigations the following conclusions can be drawn for the dry turning of stainless steel 304 material:

1. The wear rate of the tool increased when the tool is made a cathode and the work piece as anode. The tool wear rate was much higher when compared to normal turning operation in the absence of external electric current.
2. When the tool was made as anode the tool wear rate was reduced and the wear was lower compared to normal turning operation in the absence of external electric current. Improvement in machining of steel was also observed.

The insert flank wear length values for 560 mm of cutting are 147 µm, 196 µm and 124 µm for neutral, negative and positive polarities of the insert respectively.

Thus it can be said that application of DC has effect on tool wear and from the above findings making tool as anode is the way to reduce tool wear.

Lubricating fluids which can be used in conjunction with the application of electric current to reduce tool wear have to be studied. The chemical composition changes of contact surfaces have to be studied.

References

[1] K. Endo, Y. Fukuda, O. Takamiya, Wear behaviors of metals under lubricated condition and the effect of small electric potential, Bull JSME 14 (1971) 1281–1288.

[2] H. Wistuba, The effect of an external electric field on the operation of an aluminum oxide-cast iron sliding contact joint, Wear 208 (1997) 113–117.

[3] M. El Mansoria, F. Pierrona, D. Paulmier, Reduction of tool wear in metal cutting using external electromotive sources, Surface and Coatings Technology 163 –164 (2003) 472–477.

[4] A. Gangopadhyay, G. Barber, H. Zhao, Tool wear reduction through an externally applied electric current, Wear 260 (2006) 549-553.

[5] Gwidon Stachowiak, Andrew W Batchelor, Wear due to electrical discharges and passage of electric current across a contact, Engineering Tribology, Third Edition 642-643.

[6] F.H.Scott, High-temperature sliding wear of metals, Tribology International 35 (2002) 489-495.

[7] F.H.Scott, The role of oxidation in the wear of alloys, Tribology International Vol. 31, Nos. 1–3, pp. 61–71, 1998.
[8] M. Xavior, M. Adithan, Determining the influence of cutting fluids on tool wear and surface roughness during turning of AISI 304 austenitic stainless steel, journal of materials processing technology 209 (2009) 900–909.
[9] A. Kulkarni, G. Joshi, V. Sargade, Dry turning of AISI 304 austenitic stainless steel using AlTiCrN coated insert produced by HPPMS technique, Procedia Engineering 64 (2013) 737-746.
[10] X. Luo, K. Cheng, R. Holt, X. Liu, Modeling flank wear of carbide tool insert in metal cutting, Wear 259 (2005) 1235–1240.
[11] A. Attanasio, E. Ceretti, C. Giardini, C. Cappellini, Tool Wear in Cutting Operations: Experimental Analysis and Analytical Models, Journal of Manufacturing Science and Engineering 135(2013) / 051012.