Tool Condition Monitoring While Hard Turning EN19 Alloy Steel Using Coated Carbide Insert

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Abstract – This paper presents study of tool condition monitoring of Titanium Aluminium Nitride coated carbide insert while hard turning EN 19 alloy steel. A set of experiments were performed on CNC lathe with coolant. Cutting forces were measured by Kistler piezo-electric dynamometer. Tool flank wear was measured by tool maker's microscope. Influence of cutting speed, feed rate and depth of cut on tool wear is investigated. Experiments were conducted by varying one cutting parameter at a time. In this study, depth of cut is 0.3mm and it is kept constant throughout the experiment. Graphs are plotted to find the relation between cutting force and tool wear. Experimental results show that three directional cutting force components increase with flank wear. Among three components of cutting forces, tangential cutting force is largest and radial cutting force is smallest. Tangential cutting force component increases sharply when tool wear increases.

Keywords— Hard Turning, Coated Carbide Insert, Tool Condition Monitoring, Cutting Forces, Tool Wear

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INTRODUCTION

Manufacturers are constantly striving for lower cost solutions in order to maintain competitiveness in market. Part quality is continuously improving while the pressure for reducing unit cost is enormous. Now, the trend is toward high quality, lower cost and smaller batch size. Hard turning is one of the solutions to lower the cost. Hard turning can be defined as the process of single point cutting of part pieces that have hardness value over 45 HRc. Hard turning operation has the advantages of cost, time and coolant saving compared to grinding operation. Typically cubic boron nitride (CBN) and ceramic cutting tools are used in hard turning and to lower the cost of tool, there is option of coated carbide insert. The biggest challenge for hard turning operation is the surface quality whether that is close to grinding or not. Therefore, it is essential to monitor tool wear and optimize process parameters. To monitor tool wear, there are two sensing methods namely direct and indirect sensing method. Direct method has the advantages of capturing actual geometric changes arising from the wear of tool. However, it has limitations of inaccessible cutting area and continuous contact between tool and work-piece. In indirect method, tool condition is achieved from measurable parameters through sensor signals. Indirect tool condition monitoring system consists of collection of data, signal processing, and estimation of tool wear and development of decision making technique. Sensing cutting forces, vibrations, temperature and acoustic emissions are the indirect sensing methods [1]. Cutting force sensing method is beneficial because gradual change in tool wear causes increase in cutting force. Vibration signals provide thorough insight in metal cutting process. Tool vibration results in poor surface finish and tool wear. Vertical components of both cutting forces and vibration signature are the most sensitive to tool wear [2]. When feed and cutting force parameters are correlated to flank wear, it is observed that these parameters are more sensitive to changes in cutting conditions. The crater wear prediction is less accurate because of opposing effects of crater and flank wear component on cutting force components [3]. Experiments are conducted to find out relationship between flank wear and cutting forces and it is found that tangential cutting force component is sensitive to tool wear [4]. The details of work and tool material are presented in following section.

WORK AND TOOL MATERIALS

Workpiece material

EN19 alloy steel is chromium, molybdenum, manganese containing low alloy steel. It has high fatigue strength, abrasion and impact resistance, toughness, and torsional strength. It is used to make bolts, connecting rods, axle shaft, ejectors, crankshafts, tool holders. Work-piece material is of size (Ø30×100mm).Table I below given the composition of work material.

TABLE I Chemical Composition

Element	Content (%)
C	0.443
Cr	1.03
Fe	97.1
Mn	0.769
Mo	0.217
P	0.0119
Si	0.231
S	0.0253

Procedure followed for hardening of EN19

EN19 was preheated at 450^{0}C for 90 minutes then heated up to 850^{o}C and temperature is maintained for 90 minutes and followed by oil quenching. Temperature of oil was at 50^{o}C for 30 minutes. After oil quenching, tempering was carried out at 350^{o}C for 120 minutes. By following this procedure, hardness obtained is 54 HRc.

Tool material

Tool insert is made by Kyocera. Tool insert designation is TNMG160408 MS PR1125 insert. It has coating of titanium aluminium nitride (TiAlN). TiAlN is high performance coating for increased cutting parameters and higher tool life and also suitable for dry machining. It reduces heating of the tool. Hardness of insert is 3000HV. Thermal stability is up to 800^0-900^{0}C. MTJNR 2020 K-16 tool holder is used. In the following section, experimental procedure is described in brief.

EXPERIMENTATION

Experimentation is carried out on Mtab maxturn plus+ CNC lathe machine. A Kistler 9272 dynamometer with data acquisition system is used to acquire data of cutting forces. Tool post is mounted on dynamometer. Face plate attachment is used for mounting of dynamometer. The following procedural steps have been implemented.

1. Each test started with a fresh cutting edge and work-piece is machined eight times for each test. At the end of every 8th pass, measurement of tool wear and surface roughness are carried out.

2. Cutting forces were measured at 1st, 4th,5th and 8thpass of cut.

3. The cutting parameters are then modified. As per new test condition and the machine is loaded with new workpiece. Steps 1 and 2 are repeated for remaining test conditions.

Cutting parameters are varied one at a time. When cutting speed is varied from 40 to 90 m/min at that time feed rate and depth of cut are kept constant. When feed rate is varied from 0.02 to 0.17 mm/revolution at that time cutting speed and depth of cut are kept constant. Depth of cut is kept constant throughout the experiment. Experiments are carried out for finishing operation. In finishing operation surface integrity and dimensional accuracy are of primary concern. Tool wear affects dimensional accuracy and surface roughness. Correlation between cutting force, tool wear and surface roughness is found out with the help of experimental results. The results of the experiments are given in table II below.

EXPERIMENTAL RESULTS

Table II Experimental Results at Different Cutting Speeds

Cutting speed (m/min)	Feed rate (mm/revolution)	Depth of cut (mm)	No. of passes	Cutting force (N)			Surface-roughness Ra (μm)	Tool flank wear (μm)
				Tangential force (Fx)	Axial force (Fy)	Radial force (Fz)		
40	0.05	0.3	1	101	85	33	0.112	58
			4	104 (2.97)	93 (9.41)	36 (9)		
			5	123 (18.29)	102 (9.67)	31 (13.88)		
			8	138 (12.19)	103 (0.9)	38 (22.58)		
50	0.05	0.3	1	134	90	43	0.136	64
			4	117 (14.52)	91 (1.11)	44 (2.32)		
			5	119 (1.70)	92 (1.09)	40 (9.09)		
			8	144 (21)	97 (5.43)	41 (2.5)		
60	0.05	0.3	1	200	85	50	0.405	70
			4	214 (7)	103 (21.17)	62 (24)		
			5	232 (8.41)	106 (2.91)	61 (1.61)		
			8	286 (23.27)	114 (7.54)	80 (31.14)		
70	0.05	0.3	1	244	101	78	0.378	222
			4	242 (0.8)	102 (0.9)	80 (2.56)		
			5	268 (10.74)	103 (0.9)	85 (6.25)		
			8	404 (50.74)	117 (13.59)	133 (56.47)		
80	0.05	0.3	1	213	90	79	0.315	232
			4	236 (10.79)	100 (11.11)	95 (20.25)		
			5	253 (7.20)	102 (2)	97 (2.1)		
			8	446 (76.28)	130 (27.45)	159 (63.91)		
90	0.05	0.3	1	418	118	157	0.326	249
			4	627 (50)	144 (22.03)	256 (63.05)		
			5	659 (5.1)	165 (14.58)	288 (12.5)		
			8	742 (12.59)	172 (4.24)	327(13.54)		

At different test conditions, response variables are monitored. From the table we can say that tangential cutting force is more than axial and radial cutting force. As the number of passes increase cutting forces gradually increase. The variations of cutting forces with number of passes at different test conditions are plotted in figure 2 to 7 below.

Fig. 1 Experimental setup

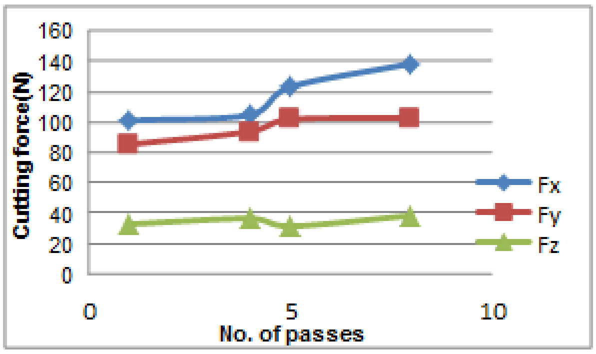

Fig. 2 Cutting speed(v) vs. Number of passes(v=40m/min, feed rate=0.05mm/revolution, depth of cut=0.3mm)

From fig.2, it is evident that the cutting forces increase from 1st pass to 8th pass. Fx increases by 36.69%, Fy increases by 20.49% and Fz increases by 17.36%.

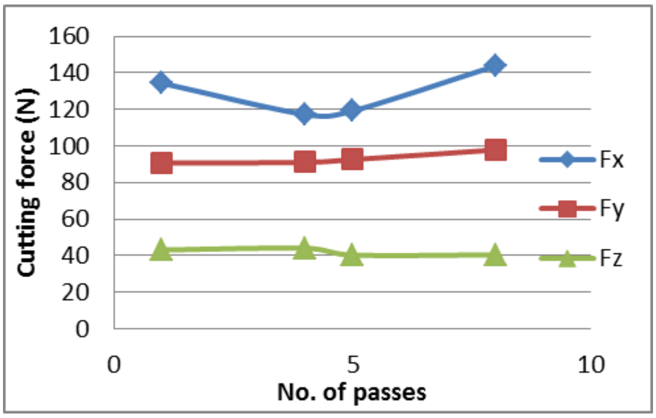

Fig. 3 Cutting speed (v) vs. Number of passes (v=50m/min, feed rate=0.05mm/revolution, depth of cut=0.3mm)

Fig.3 shows that the cutting forces increase from 1st pass to 8th pass. Fx increases by 7.148%, Fy increases by 7.89% and Fz decreases by 6.79%.

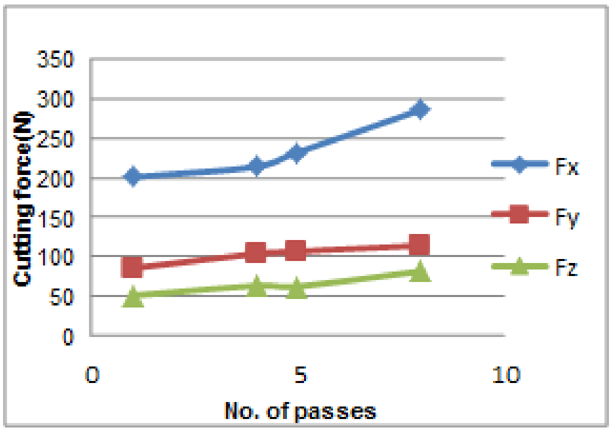

Fig. 4 Cutting speed (v) vs. Number of passes (v=60m/min, feed rate=0.05mm/revolution, depth of cut=0.3mm)

From fig.4, it is seen that the cutting forces increase from 1st pass to 8th pass. Fx increases by 42.69%, Fy increases by 34% and Fz increases by 61.37%.

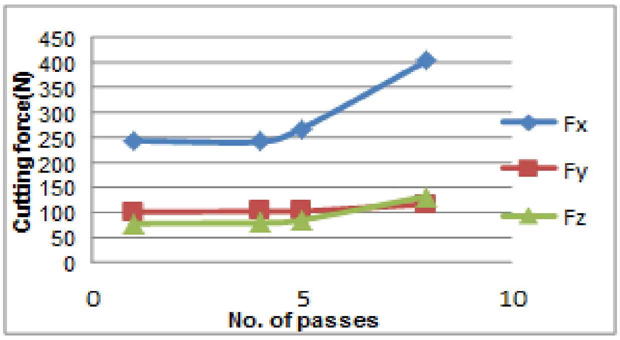

Fig. 5 Cutting speed (v) vs. Number of passes (v=70m/min, feed rate=0.05mm/revolution, depth of cut=0.3mm)

From fig.5, it is seen that the cutting forces increase from 1st pass to 8th pass. Fx increases by 65.42%, Fy increases by 15.96% and Fz increases by 68.93%.

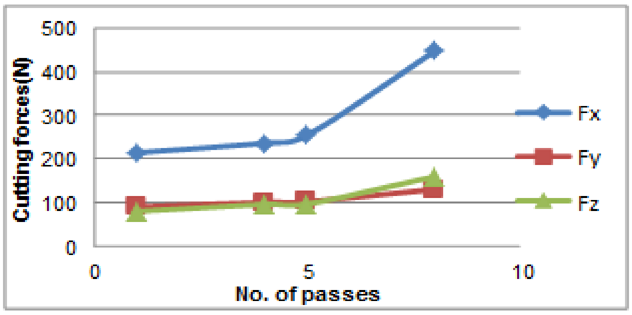

Fig. 6 Cutting speed(v) vs. Number of passes(v=80m/min, feed rate=0.05mm/revolution, depth of cut=0.3mm)

From Fig.6, we find that the cutting forces increase from 1st pass to 8th pass. Fx increases by 109%, Fy increases by 44.69% and Fz increases by 101%.

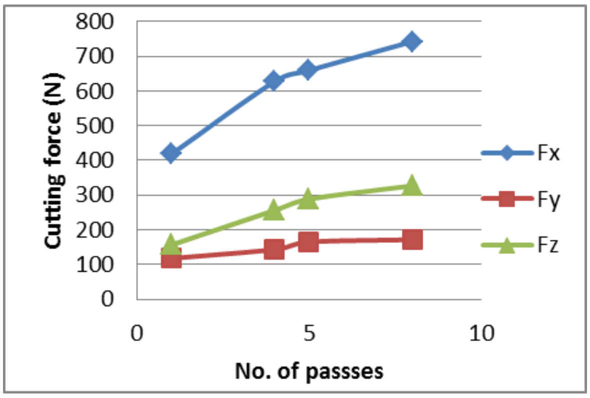

Fig. 7 Cutting speed (v) vs. Number of passes (v=90m/min, feed rate=0.05mm/revolution, depth of cut=0.3mm)

From fig.7, it is evident that the cutting forces increase from 1st pass to 8th pass. Fx increases by 77.19%, Fy increases by 45.27% and Fz increases by 107.9%.

Table III Experimental Results at Different Feed Rates

Cutting speed v (m/min)	Feed rate (mm/revolution)	Depth of cut (mm)	Number of passes	Cutting force (N) Tangential force (Fx)	Axial force (Fy)	Radial force (Fz)	Surface roughness (µm)	Tool flank wear (µm)
60	0.02	0.3	1	142	49	37	0.369	53
			4	139 (2.11)	69 (40.81)	65 (75.67)		
			5	146 (5.03)	72 (4.34)	58 (10.76)		
			8	170 (16.43)	79 (9.72)	68 (17.24)		
60	0.05	0.3	1	191	105	81	0.561	59
			4	206 (7.85)	98 (6.67)	75 (7.40)		
			5	217 (5.33)	99 (1.02)	73 (2.66)		
			8	283 (30.41)	108 (9.06)	96 (31.50)		
60	0.08	0.3	1	221	79	72	0.374	65
			4	224 (1.35)	130 (64.55)	75 (4.16)		
			5	223 (0.4)	132 (1.53)	75 (0)		
			8	287 (28.69)	139 (5.3)	88 (17.33)		
60	0.11	0.3	1	192	150	62	0.596	69
			4	194 (1.04)	152 (1.33)	65.9(6.29)		
			5	202 (4.12)	155 (1.97)	65.71(0.2)		
			8	271 (34.15)	163 (5.16)	79 (20.22)		
60	0.14	0.3	1	316	176	84	1.293	221
			4	430 (36.07)	198 (12.5)	113 (34.52)		
			5	541 (25.81)	204 (3.03)	154 (36.28)		
			8	975 (80.22)	272 (33.33)	287 (86.36)		
60	0.17	0.3	1	266	174	70	1.609	280
			4	326 (22.55)	215 (23.56)	95 (35.71)		
			5	371 (13.8)	226 (5.11)	104 (9.47)		
			8	809 (118)	255 (12.83)	202 (94.23)		

Feed rate is varied as shown in table IV. Cutting speed and depth of cut are kept constant. As feed rate increases surface roughness value and tool wear increases. Tangential force component is more than radial and axial force components. When tool wear increases considerable change occurs in tangential cutting force. As cutting passes increase cutting force also increases.

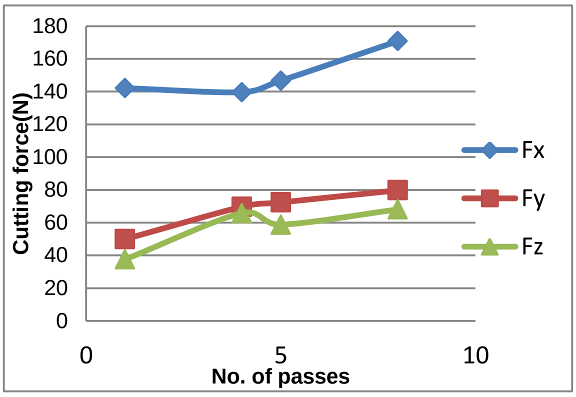

Fig. 8 Cutting speed vs. Number of passes (v=60m/min, feed rate=0.02mm/revolution, depth of cut=0.3mm)

From fig.8, it is seen that the cutting forces increasec from 1st pass to 8th pass. Fx increases by 20.19%, Fy increases by 59.79% and Fz increases by 81.07%.

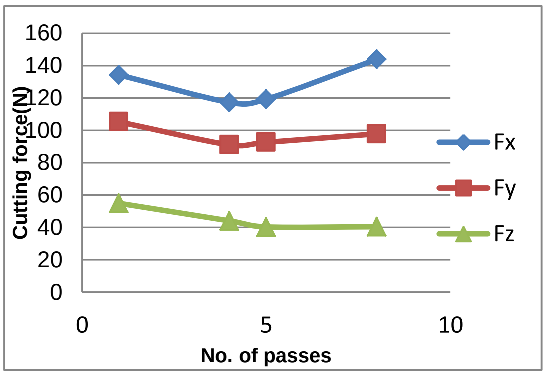

Fig. 9 Cutting speed (v) vs. Number of passes (v=60m/min, feed rate=0.05mm/revolution, depth of cut=0.3mm)

From fig.9, it is evident that the cutting forces increase from 1st pass to 8th pass. Fx increases by 48.16%, Fy increases by 3.03% and Fz increases by 18.70%.

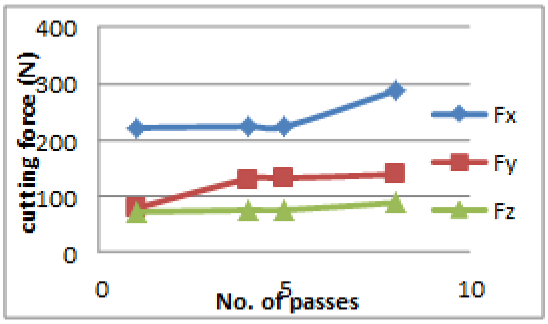

Fig. 10 Cutting speed (v) vs. Number of passes (v=60m/min, feed rate=0.08mm/revolution, depth of cut=0.3mm)

From fig.10, it is evident that the cutting forces increase from 1st pass to 8th pass. Fx increases by 29.39%, Fy increases by 75% and Fz increases by 22.10%.

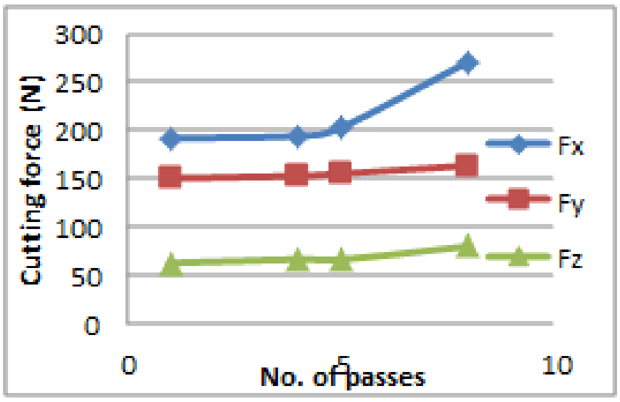

Fig. 11 Cutting speed (v) vs. Number of passes (v=60m/min, feed rate=0.11mm/revolution, depth of cut=0.3mm)

From fig.11, it is seen that the cutting forces increase from 1st pass to 8th pass. Fx increases by 41.55%, Fy increases by 8.79% and Fz increases by 27.58%.

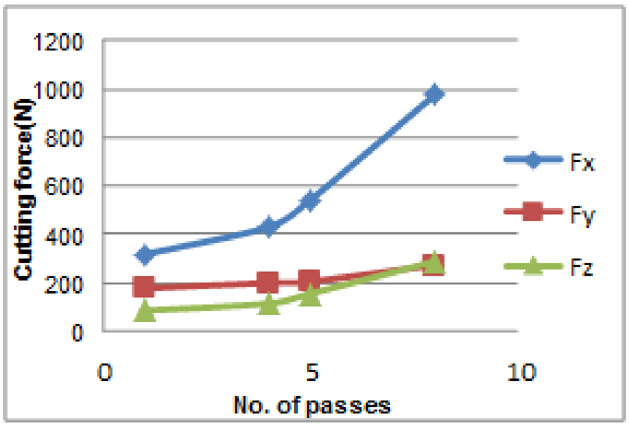

Fig. 12 Cutting speed vs. Number of passes (v=60m/min, feed rate=0.14mm/revolution, depth of cut=0.3mm)

Fig.12 shows that the cutting forces increase from 1st pass to 8th pass. Fx increases by 208%, Fy increases by 54.6% and Fz increases by 289.9%.

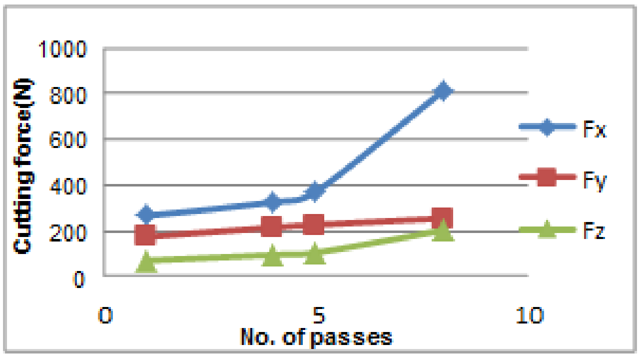

Fig. 13 Cutting speed (v) vs. Number of passes (v=60m/min, feed rate=0.17mm/revolution, depth of cut=0.3mm)

From fig.13, it is seen that the cutting forces increase from 1st pass to 8th pass. Fx increases by 204%, Fy increases by 46.6% and Fz increases by 186.9%.

From this figures, we can say that as tool wear progresses, cutting forces increase sharply. Tangential cutting force Fx is sensitive to tool wear. For cutting speeds 80 and 90 m/min. cutting forces increases suddenly. For feed rates 0.11 and 0.17 mm/revolution, sharp increase in cutting forces occurred.

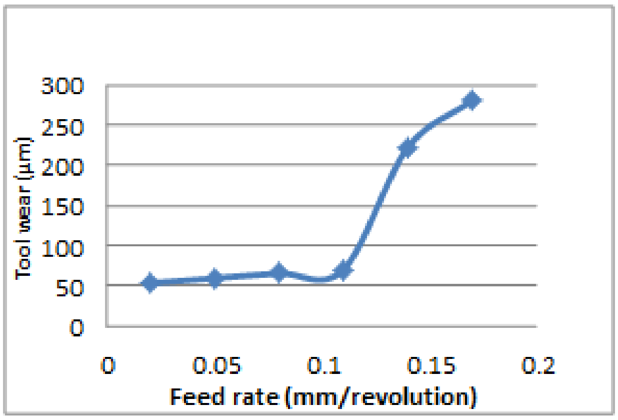

Fig. 14 Tool wear (µm) vs. feed rate (mm/revolution)

Fig. 14 indicates that, when feed rate is more than 0.11mm/revolution tool wear increases rapidly. We can say that as feed rate increases tool life decreases.

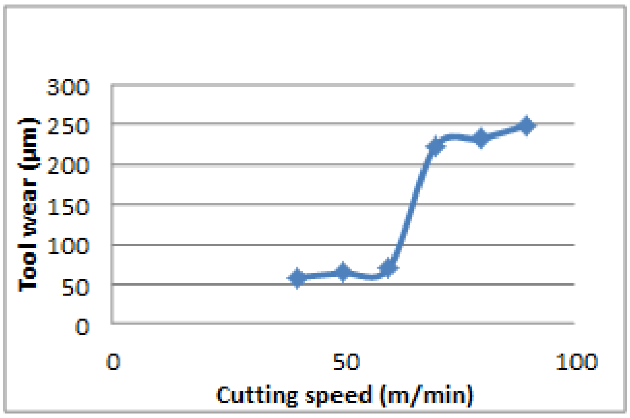

Fig. 15 Tool wear (μm) vs. cutting speed (m/min)

Fig. 15 indicates that, when cutting speed is more than 70 m/min. tool wear increases rapidly. We can say that as cutting speed increases tool life decreases.

CONCLUSIONS

Study indicates a correlation between cutting force and tool wear in hard turning operation. Increase of flank wear increases contact between insert tip and workpiece hence friction increases. Friction results in increased cutting forces. During metal cutting, tangential cutting force component is more than radial and axial force components. From the figures we can say that tangential cutting force component is sensitive to tool wear. As the number of passes increase tangential cutting force sharply increases. Tool wear values are more at feed rate 0.14 and 0.17 mm/revolution. It is observed that at cutting speed 80 and 90 m/min tool wear values are more. Here we can say that at smaller values of cutting speed and feed rate tool wear is less. Percentage increase in tool wear from cutting speed 40 to 60m/min. is 20.68%. Percentage increase in tool wear form feed rate 0.02 to 0.08 mm/revolution is 22.64%.At lower cutting speed and depth of cut tool, tool wear is less. Hence it is recommended to use cutting speed at 40 to 60 m/min. and feed rate at 0.02 to 0.08 mm/ revolution.

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