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Analysis of Roughness and Flank Wear in Turning Gray Cast Iron Using Cryogenically Treated Cutting Tools

[1]B.R. Ramji, [2]H.N. Narasimha Murthy and [2]M. Krishna
[1]Department of Manufacturing Science and Engineering, BMS College of Engineering, Bangalore, India
[2]Department of Mechanical Engineering, R V College of Engineering, Bangalore, India

Abstract: The purpose of this research was to examine the flank wear and surface roughness in turning gray cast iron using cryogenically treated carbide inserts. Turning experiments were conducted with cutting velocities: 53, 85, 99, 149 m/sec, feeds: 0.12, 0.16, 0.2, 0.24 mm/rev and a constant depth of cut: 1.5 mm. The specimens were turned using cryogenically treated and non-treated carbide inserts. The cryogenic treatment cycle consisted of cooling the test samples from room temperature to cryogenic temperature of -178.9 C in 3 h, soaking at cryogenic temperature around 24 h and warming to room temperature in about 5 h. The surface roughness (Ra, Rz, Rq and Rt μm) of the turned specimens was measured using talysurf and flank wear of the tool was measured using toolmakers microscope. The experimental layout was designed based on the Taguchi's Orthogonal Array technique and ANOVA was performed to identify the effect of the parameters on the response variables. Cryogenically treated inserts proved superior to the non-treated in all the test conditions in terms of lesser flank wear of the inserts and reduced surface roughness of the specimens. The after turned inserts were examined using Scanning Electron Microscopy for studying the flank wear mechanism.

Key words: Carbide tool, cast iron, surface finish, taguchi, wear

INTRODUCTION

The challenge of modern machining industries is mainly focused on achieving high quality in terms of workpiece dimensional accuracy, surface finish and less tool wear. The harder the material, the more difficult it is to machine. Cast iron has been used in large quantities for years because of desirable properties as good castability, good machinability and low cost. This is brittle, weak and is not malleable. A wide variety of Gray Cast Iron is used in industries for various applications. Machinability of Cast Iron is affected by the amount of carbon. Cryogenic treatment is a process similar to heat treatment. In this method, samples are cooled down to cryogenic temperature and maintained at this temperature for a long time and then heated back to room temperature to improve wear resistance and dimensional stability (Gruman Aircraft Engineering, 1965; Ahmed, 2004,). There are a lot of applications of cryogenic treatment or processing to enhance wear resistance and strength of tool materials from end mills to guillotine knives in industry (Fillipi and Ippolite, 1971). Most of the studies examined the flank wear formation since in practice; the amount of flank wear is used more frequently in determining the tool life (Kitagawa and Maekawa, 1990). Ezugwu *et al.* (1991) analyzed the differences in tool performance between cryogenically treated and untreated inserts depending on different cutting periods and breaks in turning of ASSAB 760 medium carbon steel. They obtained reductions in flank wear between 4 and 20% and increases in tool life between 1.05 and 1.3 times. The same authors have investigated cryogenically treated tungsten carbide tool performance during the high-speed face milling of the same material. Cryogenically treated inserts performed an increase of up to 38.6% in tool life over the untreated inserts in dry and wet cutting conditions in their results. Several authors (Carter, 1956; Shaw, 1986; Adler *et al.*, 2006) have reported contrasting results of tool performance in case of cryogenically treated tools used for drilling, milling, turning, etc. However, the effect of cryogenic treatment on the tool wear and surface roughness of the job in turning of Gray Cast iron is scarce. This paper is aimed at examining the tool performance in terms of flank wear and surface roughness in turning of Gray Cast iron using design of experiments and SEM.

MATERIALS AND METHODS

Experimental investigation: The turning exercises on Gray Cast iron and the study of the influence of cryogenic treatment of the inserts on the flank wear and surface

Corresponding Author: B.R. Ramji, Department of Manufacturing Science and Engineering, BMS College of Engineering, Bangalore, India

Table 1: Experimental conditions

Machine tool	High speed engine lathe
Work specimens	
Material	Gray Cast Iron(C-3.4 %, Si -1.8 %, Mn-0.5%)
Size	ϕ 30 X 150 mm
Cutting tool	SNMG 12 04 04, Uncoated
Tool Holder	PSBNR2020 K12(ISO Specification), WIDIA
Working tool geometry	Inclination angle: -6°
	Orthogonal rake angle: -6°
	Auxiliary cutting edge angle: 15°
	Principal cutting edge angle: 75°
	Nose radius: 0.4 mm
Process parameters	Cutting velocity, A: 53, 85, 99, 149 m/min
	Feed rate, B: 0.12, 0.16,0.20, 0.24 mm/rev
	Depth of cut : 1.5 mm
	Tool condition, C: Cryogenically treated (CT) , Untreated (NT)
Measuring instruments	Talysurf (SJ-201) for surface roughness (Ra, Rz, Rq, Rt)
	Toolmakers microscope (TM-505/505R) Eye piece: 15X, Objective: 2X, for measuring flank wear in mm
	Scanning Electron Microscope: JOEL
Place of study	R.V. College of Engineering Bangalore, India
Time of study	January 2008

Table 2: Factors, levels and degrees of freedom

Factor code	Factor	No. of levels	df
A	Cutting velocity	4	3
B	Feed rate	4	3
C	Tool condition	2	1
A X B	Interaction	3 X 3	9
	Total degrees of freedom		16
	Minimum number of Experiments		17

roughness of the work piece were undertaken under the experimental conditions presented in Table 1.

The cryogenic treatment involved cooling the inserts from room temperature to cryogenic temperature (-178.9ºC) in 3 h, soaking at this temperature for 24 h and warming to room temperature in 5 h in accordance with Ezugwu *et al*. (1991). Turning exercises were undertaken for each experimental condition for duration of 10 min to maintain uniformity.

Design of experiments: The total degrees of freedom was computed as shown in Table 2 to arrive at the minimum number of experiments as per orthogonal array experimentation technique. An L_{32} Orthogonal Array Experimental layout was selected to satisfy the minimum number of experiments condition and the experimental layout is presented in Table 3 along with the responses.

ANOVA of the responses: The analysis of variance based on the responses obtained in the turning exercises is presented in Table 4 and 5 for flank wear and surface roughness, respectively.

RESULTS AND DISCUSSION

In turning flank wear is an indicator of tool life. The tool wear is caused by abrasive, diffusive and adhesive wear mechanisms. The heat generated during turning also affects tool life. At higher speeds the sliding distance of cutting tool increases for a given time. Also, greater amount of heat is generated at higher speeds. The combined effect of these increases wear and the plastic deformation of the cutting edge (Stephenson and Agapiou, 1997). Surface finish is an important index of machinability because life and performance of the machined components are influenced by their surface finish, residual stresses and surface defects (Paul *et al*., 2001). The surface quality largely depends upon the stability of the cutting nose and the dimensional accuracy is controlled by the flank wear of turning tools. The ANOVA indicated that, the cryogenic treatment influenced flank wear and surface roughness to the extent of 31 and 34% respectively. Cutting velocity influenced the flank wear by 49.77% and surface roughness by 25.88%. Whereas the influence of the feed rate on the flank wear was moderate to the extent of 14.4%, the same on the surface roughness was very significant (37.73%). Cryogenic treatment of the inserts influenced both flank wear and surface roughness nearly to the same extent (31.75 and 34.42%, respectively). None of the interaction effects was found significant for both flank wear and surface roughness. Rake angle of the turning tool affects flank wear and hence negative rake angle of -6° was selected for turning.

Scanning electron microscopy: The Fig. 1 shows SEM of the treated and nontreated turned inserts which were examined to analyse the effect of cryogenic treatment.

Table 3: Experimental layout

Ex. No.	Cutting Velocity (m/sec)	Feed (mm/rev)	Tool condition (CT/NT)	Flank wear (mm)	Ra (µm)
1	53	0.12	CT	1.07	1.28
2	53	0.12	NT	1.35	1.40
3	53	0.16	CT	1.16	1.34
4	53	0.16	NT	1.43	1.49
5	53	0.20	CT	1.21	1.39
6	53	0.20	NT	1.52	1.56
7	53	0.24	CT	1.29	1.51
8	85	0.24	NT	1.56	1.66
9	85	0.12	CT	1.32	1.30
10	85	0.12	NT	1.43	1.53
11	85	0.16	CT	1.23	1.37
12	85	0.16	NT	1.50	1.56
13	85	0.20	CT	1.29	1.44
14	85	0.20	NT	1.6	1.65
15	85	0.24	CT	1.35	1.60
16	85	0.24	NT	1.65	1.75
17	99	0.12	CT	1.41	1.34
18	99	0.12	NT	1.57	1.60
19	99	0.16	CT	1.48	1.44
20	99	0.16	NT	1.62	1.65
21	99	0.20	CT	1.54	1.53
22	99	0.20	NT	1.68	1.73
23	99	0.24	CT	1.60	1.69
24	99	0.24	NT	1.75	1.84
25	149	0.12	CT	1.48	1.40
26	149	0.12	NT	1.632	1.68
27	149	0.16	CT	1.55	1.52
28	149	0.16	NT	1.71	1.73
29	149	0.20	CT	1.60	1.61
30	149	0.20	NT	1.80	1.82
31	149	0.24	CT	1.68	1.73
32	149	0.24	NT	1.92	1.93

Table 4: ANOVA for flank wear

SV	df	SS	MS = SS/DOF	F_{cal} = MS/MS_{error}	F_{tab}	Contribution (%)
A	3	0.5862428	0.1954143	165.61	3.86	49.77
B	3	0.1697466	5.658219E-02	47.95	3.86	14.41
C	1	0.374026	0.374026	316.99	5.12	31.75
A*B	9	9.7917E-03	1.087966E-03	0.922	3.18	0.55
B*C	3	5.5052E-03	1.835055E-03	1.555	3.86	0.30
A*C	3	2.1778E-02	7.259472E-03	6.1526	3.86	1.22
ERROR	9	1.06191E-02	1.179899E-03			0.59
Total	31	1.1777				100

SV = Source of Variation

Table 5. ANOVA for surface roughness (*Ra*)

SV	df	SS	MS = SS/DOF	$F_{cal=}$ = MS/MS_{error}	F_{tab}	Contribution (%)
A	3	0.2243	7.4770E-02	175.7786	3.86	25.88
B	3	0.3271	0.1091	256.3273	3.86	37.73
C	1	0.2984	0.2984	701.4933	5.12	34.42
AB	9	3.05E-03	3.3924E-04	0.7975	3.18	0.0035
AC	3	6.4844E-03	2.1615E-03	5.0816	3.86	0.0074
BC	3	3.6594E-03	1.2198E-03	2.8677	3.86	0.0042
Error	9	3.828E-03	4.2535E-04			0.00
Total	31	0.8667				100

SV = Source of Variation

The main cutting edge of non treated insert was found to suffer from chipping as shown in SEM of Fig. 1c, d. Cryogenic cooling hardened the inserts and increased wear resistance as shown in Fig. 1a, b. The increase in hardness due to transformation of austenite to martensite as shown in Fig. 1a expectedly reduced flank wear and surface roughness.

CONCLUSION

Cryogenic treatment of the inserts proved better than the non-treated ones in terms of less flank wear and better surface finish of Gray cast iron specimens. The extents of influence of cutting velocity, feed and the condition of the inserts were examined by conducting orthogonal array

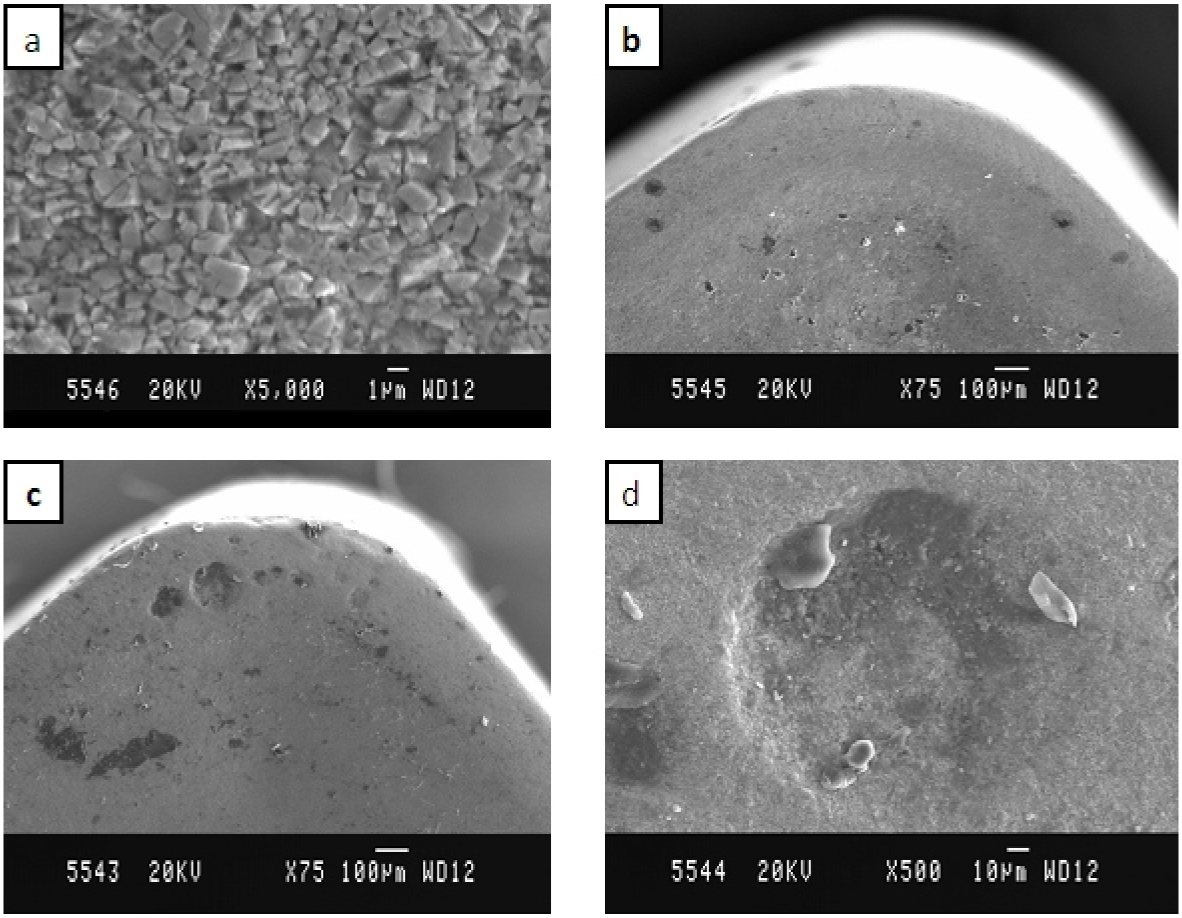

Fig. 1: SEM of after turned carbide inserts at cutting velocity of 149 m/min, feed: 0.24 mm/rev, a) Microstructure of treated insert shows martensite phase, b) Reduced wear of cutting edge in Treated insert, c) Increased wear of cutting edge of non treated insert, d) Chipping of cutting edge in non treated Insert

experimentation. The responses obtained after turning the specimens for ten minutes in each case were analyzed. Further experiments with cryogenically treated coated inserts for longer duration have been planned to examine the reduction in flank wear and surface roughness as a function of time. Cryogenic treatment can enable significant improvement in both productivity and product quality and hence overall machining economy offsetting the cost of cryogenic cooling.

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