Machining force comparison for surface defect hard turning and conventional hard turning of AISI 52100 steel

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Abstract: *In this article, a recently developed method called surface defect machining (SDM) for hard turning has been adopted and termed surface defect hard turning (SDHT). The main purpose of the present study was to explore the impact of cutting parameters like cutting speed, feed, depth of cut, and tool geometry parameters such as nose radius and negative rake angle of the machining force during surface defect hard turning (SDHT) of AISI 52100 steel in dry condition with Polycrystalline cubic boron nitride (PCBN) tool; and results were compared with conventional hard turning (CHT). Experimentation is devised and executed as per Central Composite Design (CCD) of Response Surface Methodology (RSM). Results reported that an average machining force was decreased by 22% for surface defect hard turning (SDHT) compared to conventional hard turning (CHT).*

Key Words: *Surface defect machining, Surface defect hard turning, Machining force, AISI 52100 steel, hard turning, conventional hard turning*

1. INTRODUCTION

Hard turning (turning of material whose hardness ranges between 45-65 HRC) is proposed to be a superior alternative for grinding and gained wider acceptance [1-3]. Hard turning (HT) has more prominent adaptability in contrast with grinding, additionally it has the capacity to produce an unpredictable geometry in one set up [4]. Despite this, the cutting tool during hard turning will experience higher cutting resistance due to more tool-chip interface contact length. Moreover, the surface integrity could be spoiled by the colloidal chips. These limitations of HT caused by continuous chip could be overcome by altering the removal mechanism to chip fragmentation. With this motivation researchers incorporated the surface defects on the workpiece which acts as chip breakers while hard turning and the procedure is termed Surface Defect Machining (SDM). Turning of hard material with induced surface defects is termed as surface defect hard turning (SDHT) [5]. These defects are found in the form of holes, grooves, indentations, etc. and can be easily produced on the surface of the workpiece. Surface defect hard turning (SDHT) ensures improved surface quality, lower average cutting forces, reduced cutting zone temperature and reduced tool chip contact length.

Xianli Liu et al. [6] concluded that cutting force decreases with a rise in cutting speed in HT of GCr15 bearing steel. Anupam Alok and Manas das [7] observed low machining force at high speed with low feed and depth of cut while HT of AISI 52100 steel with PVD coated carbide tool. Liu et al. [8] determined the effect of cutting conditions on cutting force while turning of GCr15 steel using the PCBN tool. Results concluded that cutting force rises with the raise of workpiece hardness.

Sateesh Kumar and Saroj Kumar Patel [9] concluded that usage of coated tools offered a reduction of machining forces compared to uncoated tools in HT of AISI 52100 steel. Ouahid Keblouti et al. [10] concluded that cutting force was remarkably influenced by the depth of cut in HT of AISI 52100 steel deploying uncoated and coated (with TiCN-TiN) cermet tools. Ildikó Maňková et al. [11] observed that with an increase in feed the cutting force increases in HT of 100Cr6 bearing steel. Meddour et al. [12] reported that the force was significantly influenced by the depth of cut followed by feed rate in HT of AISI 52100 steel using ceramic tools. Azizi et al. [13] revealed that an increase in workpiece hardness and cutting time increases cutting forces while bearing steel turning. Rashid et al. [14] deployed FEM modeling to relate the conventional hard turning (CHT) of AISI 4340 steel with the SDM method. Results revealed that compared to conventional hard turning, SDM provided reduced average cutting forces and tool-chip interface contact length.

Rashid et al. [15] carried out investigation while HT of AISI 4340 steel using the CBN tool. Surface defects were generated in the form of holes on the workpiece surface. Results reported that better quality of machined surface and lower average cutting forces are obtained over conventional hard turning. Amir Mir et al. [16] proposed SDM in turning with various defect profiles of silicon using smooth particle hydrodynamics (SPH) simulation approach and concluded that increased tool life and better surface finish was obtained by reducing cutting resistance. Results also revealed that SDM with round profile defects yielded minimum thrust force. Umamaheswar Rao et al. [17-20] optimized process parameters in HT of AISI 52100 steel through GRA-PCA.

From the literature, it is clear that the scanty literature/work was available on the application of SDM for HT of AISI 52100 steel. Earlier studies applied the drilled holes as surface defects which may lead to intermittent tool workpiece contact results in relaxation and loading on the tool suddenly. This can be minimized by replacing cylindrical holes with a spherical indentation which may result in relaxation and loading on the tool gradually which is preferable for the machining process. Hence, the present work examined the impact of cutting and tool geometry parameters on machining force in surface defect hard turning (SDHT) of AISI 52100 steel.

2. EXPERIMENTAL DETAILS

The surface defects were created on the workpiece in the form of indentations. The depth of indentation was 0.25 mm and indentations were spaced at 10 mm intervals along the circumference of the workpiece for every 90°.

Table 1. State of machining of AISI 52100 steel

Machining conditions	Notation	Descriptions
Workpiece material		AISI 52100 steel
Dimensions		48 mm diameter and 500 mm length
Hardness		57 HRC
Cutting speed	ν	200, 400, 600, 800, 1000 rpm
Feed	f	0.02, 0.04, 0.06, 0.08, 0.1 mm/rev
Depth of cut	d	0.4, 0.5, 0.6, 0.7, 0.8 mm
Nose radius	r	0.4, 0.6, 0.8, 1, 1.2 mm
Negative rake angle	α	-5, -15, -25, -35 and -45
Cutting environment		Dry
Cutting inserts/tool		Polycrystalline cubic boron nitride (PCBN)
Tool holder		PSBNR 2525 M12
Tool geometry		CNMG120404, CNMG120406, CNMG120410, CNMG120412
Type of defect		Indentation
Spacing between indentations		10 mm
Machining length for each experiment		30 mm
Response	F_M	Machining force

Fig. 1 Workpieces without surface defects (CHT)

Fig. 2 Workpieces with surface defects

Fig. 3 Experimental setup

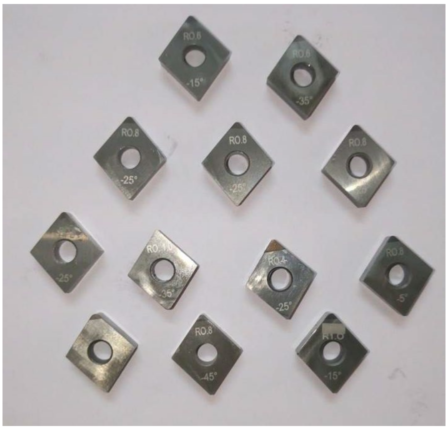

Fig. 4 PCBN inserts

AISI 52100 steel with a hardness of 57 HRC having 500 mm length and 50 mm diameter was used as a workpiece in the present study. Machining trials were performed on Kirloskar turn master-35 lathe in dry condition. PCBN inserts with diverse nose radii range from 0.4 to 1.2 mm with an increment of 0.2 mm, with different negative rake angles (-5, -15, -25, -35 and -45) were deployed for experimentation. Cutting inserts were mounted on the PSBNR2525 M12 tool holder. The machining conditions of the present work are summarized in Table 1. Workpieces with and without surface defects are depicted in Figure 1. & Figure 2. Experimental setup is shown in Figure 3. Five machining parameters were varied at five levels throughout hard turning, and their influence on machining force was examined. The experimental runs are designed using CCD of RSM. Two sets of machining trials were carried out in this study, the first set being conventional hard turning (CHT) and the second being the induced surface defect hard turning (SDHT). For both sets, identical machining parameters were used. The cutting forces were measured in real time with a Kistler three-component dynamometer. PCBN inserts are shown in Figure 4.

3. RESULTS AND DISCUSSIONS

Experimental matrix with response is presented in Table 2. Machining force variation with respect to cutting and tool geometry parameters for both CHT and SDHT were discussed.

3.1 Effect of cutting speed on machining force

From Figure 5. it can be seen that, for CHT, the thermal softening [21-22] was the major factor responsible for the reduction in machining force dominating the cutting resistance, whereas for SDHT because of the presence of surface defects, discontinuous shearing of the chip [15] was the major reason for marginal increment in machining force overcoming increase in cutting resistance with speed.

Table 2. Experimental matrix with response

Expt. No	ν (rpm)	f (mm/rev)	d (mm)	r (mm)	α (°)	CHT-F_M (N)	SDHT-F_M (N)
1	400	0.04	0.5	0.6	35	404.735	255.856
2	800	0.04	0.5	0.6	15	233.475	405.209
3	400	0.08	0.5	0.6	15	322.117	370.140

4	800	0.08	0.5	0.6	35	473.03	256.020
5	400	0.04	0.7	0.6	15	317.493	340.044
6	800	0.04	0.7	0.6	35	376.384	360.268
7	400	0.08	0.7	0.6	35	583.032	401.546
8	800	0.08	0.7	0.6	15	380.407	328.248
9	400	0.04	0.5	1	15	273.585	282.723
10	800	0.04	0.5	1	35	425.463	283.755
11	400	0.08	0.5	1	35	561.163	412.058
12	800	0.08	0.5	1	15	350.276	306.751
13	400	0.04	0.7	1	35	443.782	259.965
14	800	0.04	0.7	1	15	323.621	401.864
15	400	0.08	0.7	1	15	411.791	341.053
16	800	0.08	0.7	1	35	523.367	380.235
17	200	0.06	0.6	0.8	25	430.828	325.724
18	1000	0.06	0.6	0.8	25	355.441	348.496
19	600	0.02	0.6	0.8	25	309.595	317.061
20	600	0.1	0.6	0.8	25	534.481	360.876
21	600	0.06	0.4	0.8	25	344.431	316.238
22	600	0.06	0.8	0.8	25	449.219	380.918
23	600	0.06	0.6	0.4	25	359.396	341.487
24	600	0.06	0.6	1.2	25	446.225	335.666
25	600	0.06	0.6	0.8	5	279.954	353.494
26	600	0.06	0.6	0.8	45	601.276	320.689
27	600	0.06	0.6	0.8	25	358.525	330.230
28	600	0.06	0.6	0.8	25	370.743	338.851
29	600	0.06	0.6	0.8	25	378.525	327.291
30	600	0.06	0.6	0.8	25	403.976	328.684
31	600	0.06	0.6	0.8	25	380.24	347.360
32	600	0.06	0.6	0.8	25	370.65	297.120

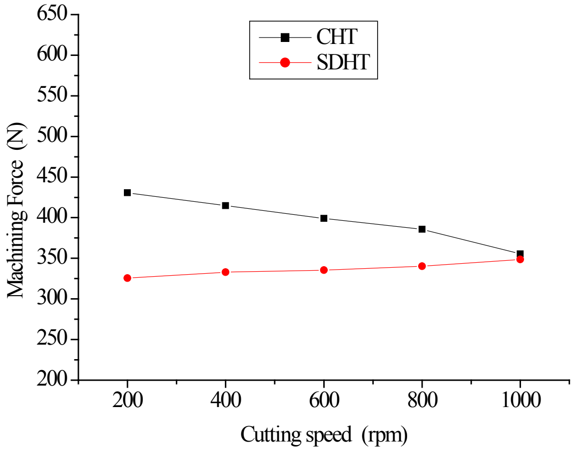

Fig. 5 Cutting Speed Vs Machining force

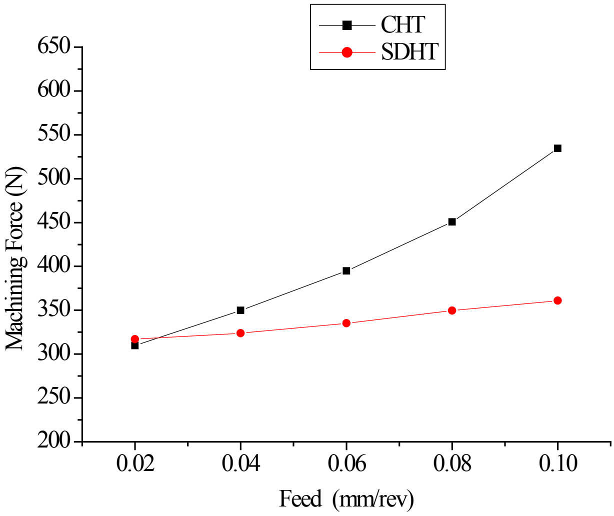

Fig. 6 Feed Vs Machining force

3.2 Effect of feed on machining force

Machining force increases almost linearly (as shown in Figure 6.) with an increase in feed for conventional hard turning (CHT) due to increased contact length and ploughing [23-24], whereas for SDHT the increment in machining force is slight or insignificant because of ease of machining irrespective of ploughing [23]. Lower machining force is observed at low feed rates i.e 0.02 mm/rev for CHT and SDHT. Lower machining force is observed for CHT at higher cutting speed i.e 1000 rpm, and for SDHT at lower cutting speed i.e 200 rpm.

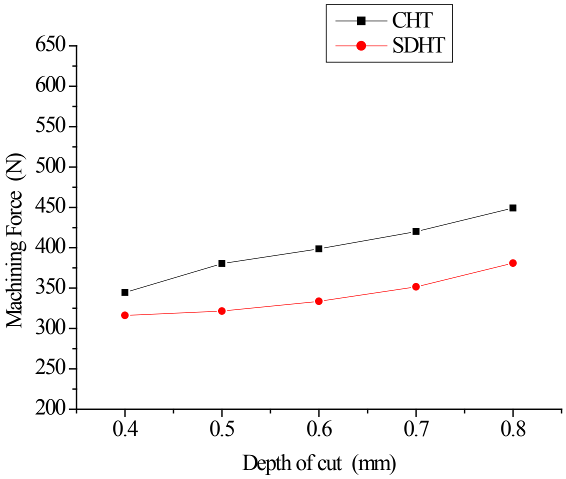

Fig. 7 Depth of cut Vs Machining force

3.3 Effect of depth of cut on machining force

As the depth of cut increases, the machining force increases steadily (as shown in Figure 7.) for CHT, due to increase in cutting resistance and tool chip interface area [23] since variation in chip thickness at surface defect zone offers less cutting resistance in SDHT resulting in minimization of increment of machining force contrasted to CHT. Lower machining forces were noticed at lower depth of cut for both CHT and SDHT.

3.4 Effect of nose radius on machining force

From Figure 8 it can be seen that the machining force increases slightly with an increase in nose radius for CHT and due to the radial force it increases significantly when the nose radius of the tool increases [25] whereas the variation in machining force is marginal for SDHT. Lower machining forces were observed at a low nose radius for CHT and SDHT almost.

3.5 Effect of negative rake angle on machining force

From Figure 9 it can be observed that the machining force increases linearly with an increment in negative rake angle for CHT due to the increased edge strength of the tool with an increase in negative rake angle causing ease in machining [23, 26].

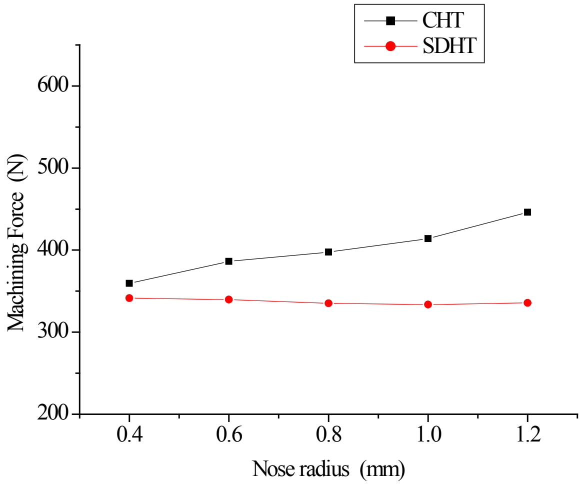

Fig. 8 Nose radius Vs Machining force

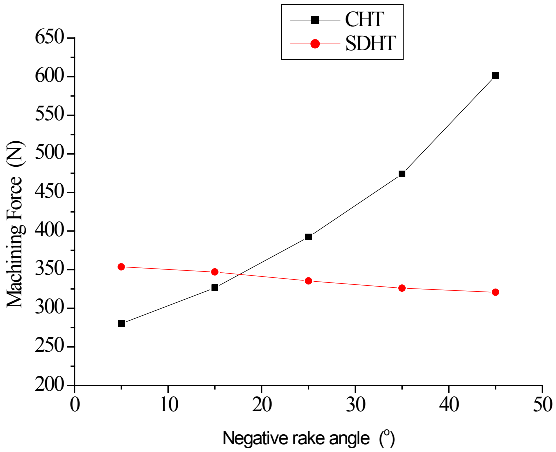

Fig. 9 Negative rake angle Vs Machining force

For SDHT minor variations in machining force were observed. Lower machining force was noticed at lower and higher negative rake angles for CHT and SDHT respectively. The obtained results in the present work are in good agreement with the results of Waleed Bin Rashid et al [27].

4. CONCLUSIONS

In the present study the surface defect hard turning (SDHT) of AISI 52100 steel was executed using PCBN tools. The study reveals that SDM can be effectively used to reduce machining forces in hard turning.

- An average of 22% drop in machining forces was observed in surface defect hard turning (SDHT) compared to conventional hard turning (CHT).
- The presence of surface defects in surface defect hard turning (SDHT) reduces the machining forces.
- The surface defects on the workpiece lead to discontinuous shearing of the material results in reduced machining forces compared to conventional hard turning (CHT).

NOMENCLATURE

PCBN	Polycrystalline cubic boron nitride	PCA	Principle Component Analysis
CCD	Central Composite Design	C	Insert shape (rhombic)
RSM	Response Surface Methodology	N	Clearance angle (0 degree)
SDM	Surface defect machining	M	Tolerances
AISI	American Iron and Steel Institute	G	Form of top surface
CBN	Cubic boron nitride	P	Clamping method (Retained via bore)
ANOVA	Analysis of Variance	S	Insert shape (square)
HRC	Hardness on Rockwell 'C' Scale	B	Style (75 degree)
DOE	Design of Experiments	N	Clearance angle (0 degree)
HT	Hard turning	R	Cutting direction (right handed)
CHT	Conventional hard turning	v	Cutting speed
SDHT	Surface defect hard turning	f	Feed
SPH	Smooth particle hydrodynamics	d	Depth of cut
FEM	Finite Element Method	r	Nose radius
PVD	Physical Vapor Deposition	α	Negative rake angle
GRA	Grey Relation Analysis	F_M	Machining force

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