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EVALUATION OF CUTTING FORCES IN HARD TURNING OF AISI 52100 STEEL BY USING TAGUCHI METHOD

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ABSTRACT

The machinability of AISI 52100 hardened steel be expressed in terms of the performance variables such as MRR, cutting forces, tool wear, surface finish and surface integrity etc. In this investigation statistical analysis of the process was performed to explore the effect of the input factors on output variables ,i.e. cutting forces (performance measures). The paper first gives background for this study,experimental setup and design are then discussed, along with the experimental observations on the cutting forces. Finally, conclusions are presented. Such knowledge will help to better understand and model the hard machining process.

Keywords: Axial force, Radial force, Cutting force, Hard Turning.

1. Introduction

Hard turning is an emerging technology that can potentially replace many grinding operations due to improved productivity (increasing production efficiency, high speed machining), increased flexibility (increasing the range of material that can be machined), decreased capital expenses (saving in cost), and reduced environmental waste[1].In hard turning, ferrous metal parts that are hardened usually between (45-70 HRc) are machined with the single point cutting tools. This has become possible with the availability of the new cutting tool materials (cubic boron nitride (CBN) and ceramics). Since a large number of operations is required to produce the finished product, if some of the operations can be combined, or eliminated, or can be substituted by the new process, product cycle time can be reduced and productivity can be improved. The traditional method of machining hardened materials includes rough turning, heat treatment, and then grinding process. Hard turning eliminates the series of operations required to produce a component and thereby reduces the cycle time resulting in productivity improvement [2-4].While most hard machining research thus far has focused on chip formation mechanisms and tool wear characterization, it is of great interest to study the effect of cutting conditions on chip morphology. It has been observed that the chip dimension changes as cutting conditions change [5] However, there is still no systematic study of cutting forces in hard machining. It can be observed by literature that cutting forces increase drastically when machining materials with hardness higher than about 45 HRc [6,]. According to results establish during hard cutting by Federico M. Aneiro et al. the radial force showed to be the highest, because the depths of cut and the feed rates selected were significantly smaller than the insert nose radius (0.8 mm). As a result, the chip sectional area was very small, which contributes to lower cutting forces [7]. The results of hard cutting, which is different from conventional cutting, indicated that in general, the radial force is the highest followed by the tangential and axial forces[8,9,10].

2. Experimental technique

2.1 Experimental setup

Hardened 52100 bearing steel with a hardness of 48~50 HRc was chosen for experimental studies because of its wide use in both automobile industry and research fields. The chemical compositions of the AISI52100 Steel are shown in the Table 1. Turning operations were performed dry using a ACE design Jobber computer numerical control lathe. The Non coated CBN cutting inserts (Mitsubishi, Japan) with a negative 5^0 rake angle and a 0.8 mm nose radius were used for turning experiments.

Table 1 Chem. composition of the work material

C	Cr	Mn	Si	S	P
0.92	1.06	0.51	0.22	0.039	0.040

The geometry and grade of insert is NP-CNMA120408G (Mitsubishi). Inserts are recommended for machining hardened steel and cast iron in finish operations. It is a highly recommended cutting tool material for hardened steel machining because is suitable for high speed finishing of heat treated steel, sintered ferrous alloy and cast iron stability at elevated temperature. Low affinity to iron, thus good surface finishes is possible.The tool holder used for clamping the insert is PCLNR 2525 M (Make- WIDIA). It has 95º approach angle and -6º back rake angle.

2.2 Experimental Design

The experimenters were performed according to Taguchi L_9 orthogonal array[11,12]. Based on the experimental work, the results are presented in this paper. It consists of the assessment cutting force components in hard turning of EN 31 Steel. Table 2 presents design layout according to L_9 design.

Table 2 Design layout according to L_9 design

Expt. No.	Cutting Speed, *V* (m/min)	Feed, *f* (mm/rev)	Depth of cut, *d* (mm)
1	250	0.03	0.1
2	250	0.04	0.2
3	250	0.05	0.3
4	300	0.03	0.2
5	300	0.04	0.3
6	300	0.05	0.1
7	350	0.03	0.3
8	350	0.04	0.1
9	350	0.05	0.2

The statistical analysis was performed in order to determine the significant factors that have more effect on the cutting force components using MINITAB15 software. The analyzed results were presented using mean effects plots and surface plots. The results predicated by ANOVA at the 95% confidence interval. Hard turning operation involves various input variables that include cutting speed, feed rate and depth of cut. These variables have direct as well as indirect effect on the performance of hard turning process. All three levels of every factor are equally represented in 9 experiments. Since the experimental design is orthogonal, it is possible to separate out the effect of each factor at each level.

3. Results and Discussion

Table 3 presents experimental results of cutting force components (Fx, Fy and Fz) for various combinations of cutting regime parameters according to L_9 design. These are the axial or feed component (Fx), radial or passive component (Fy), tangential or cutting force component (Fz)and the resultant force(Fr). The investigations prove that the radial force component is the highest in machining of external cylindrical surface.

Table 3 Experimental results for cutting force components by Kistler Dynamometer

Expt No.	Fx (N)	Fy (N)	Fz (N)	Fr (N)
1	6.561	11.3525	4.9133	14.00
2	11.93	17.8223	8.5144	23.07
3	26.24	51.2695	24.0479	62.65
4	23.40	39.1846	20.4468	50.013
5	42.38	69.1071	35.9802	85.83
6	58.04	97.3511	88.1653	143.59
7	91.94	97.3206	52.2766	143.72
8	36.22	49.8657	45.5017	76.61
9	10.43	24.4141	11.2610	28.84

While the other two force components shows less values. It is different from the force relation which is valid in the traditional cutting where the main cutting (tangential) force is the highest. The enlightenment is that the chip formation mainly occurs on the tool radius in hard turning and the machining is done with having negative rake angle.

3.1 Statistical Analysis of Axial Force (Fx)

Table 4 demonstrates the ANOVA result for axial force. It originate that the depth of cut is the most major cutting parameters for affecting the axial (feed) forces.

Table 4 ANOVA result for Axial force

Source	Sumof Squares (SS)	Degrees of Freedom (DOF)	Mean Sq. (MS)	F-Val. α=5 %	P-Val.
V	1698.6	2	849.3	0.90	0.527
f	193.5	2	96.7	0.10	0.907
d	2198.0	2	1099.0	1.16	0.462
Error	1888.8	2	944.4	--	--
Total	5978.9	8	849.3	--	--

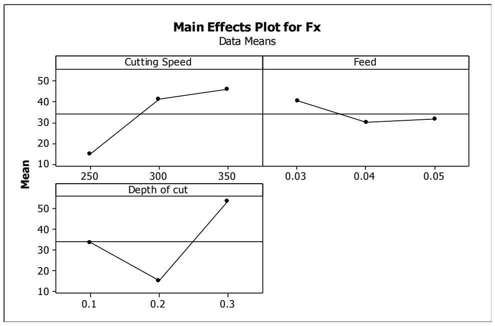

Figure 1. Main effect plot for Axial force Fx

The second factor influencing Fx is the cutting speed. The feed rate has an insignificant effect on axial force. Therefore, based on the S/N ratio and ANOVA analysis, the optimal cutting parameters axial force are the cutting speed at 250m/min, the feed rate at 0.04mm/rev, and the depth of cut at0.2mm.The effect of cutting speed, feed and depth of cut on axial force (Fx) is presented in Figure1.

The effect of cutting speed

It can be seen in Figure 1 that axial force increased as the cutting speed was increased, with different slopes. This is due to the rise in temperature in the cutting zone which makes the metal machined more plastic and consequently the efforts necessary for machining decrease.

The effect of feed rate

The effect of feed rate on cutting forces is shown in Figure1. It can be noted that the increase in feed rate resulted in the decrease increase in cutting forces.

The effects of feed rate on this force is as, the increase in feed rate from 0.03 to 0.04 mm/rev, decreases components of the cutting forces Fx.If the feed rate increases, the section of sheared chip increases because the metal resists rupture more and requires large efforts for chip removal.

The effect of depth of cut

Figure 1 represents the influence of the depth of cut on the axial forces. With its increase, chip thickness becomes significant what causes the growth of the volume of deformed metal and that

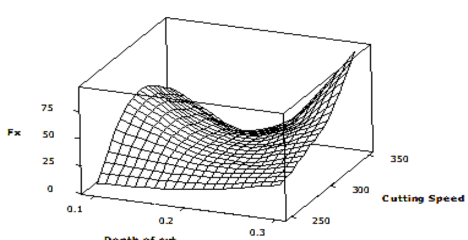

Figure 2 Surface plot of axial force (Fx) vs cutting speed and depth of cut

requires enormous cutting forces to cut the chip. forces, Fx. It is noted that the axial force is very affected by the depth of cut. The effect of machining parameters in For the depth of cut 0.2 to 0.3 mm, successively recorded the increase in components of the cutting combination is also illustrated with the help of surface plot. From Figure 2 it was observed that the cutting forces are minimum at lower values of cutting speed and depth of cut. This could be because of the reduced chip cross sectional area and the corresponding material removal rate as encountered during machining.

3.2 Statistical Analysis of Radial Force (Fy)

Table 5 displays the ANOVA for radial force. The feed rate has an insignificant effect on radial force. Therefore, based on the S/N ratio and ANOVA analysis, the optimal cutting parameters are the cutting speed at 250 m/min, the feed rate at 0.04 mm/rev., and the depth of cut at 0.2 mm.Figure 3 shows the main effect plot for radial force (Fy) for cutting speed, feed and depth of cut.

Table 5 ANOVA result for Radial force (Fy)

Source	Sumof Squares (SS)	Degrees of Freedom (DOF)	Mean Sq. (MS)	F-Val. α=5 %	P-Val.
V	2794	2	1397	1.39	0.418
f	230	2	115	0.11	0.897
d	3113	2	1557	1.55	0.392
Error	2005	2	1003	--	--
Total	8142	8		--	--

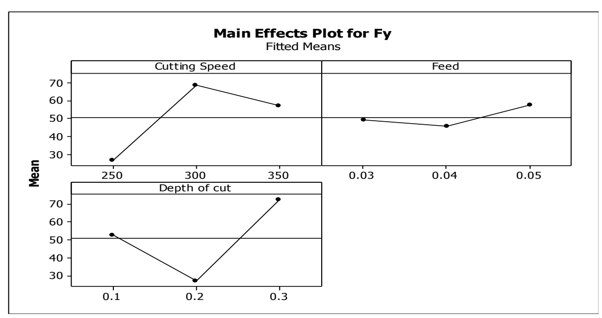

Figure 3 Main effect plot for radial force Fy

The effect of cutting speed

Figure 3 indicates that the force decreased as the cutting speed was increased in range 300-350 m/min.

The effect of feed rate

The effect of feed rate on cutting forces is shown in Figure 3. It can be noted that the increase in feed rate resulted in the increase in cutting forces from 0.04 to 0.05 mm/rev.

The effect of depth of cut

For the depth of 0.2 to 0.3 mm, recorded the increase in components of the radial forces, Fy. It is noted that the radial force is very affected by the depth of cut. In 3D surface plot Figure 4 shows that as depth of cut increases from 0.1 to 0.2 there is decrease in radial force, but for further increase in the depth of cut from 0.2 to 0.3the radial force

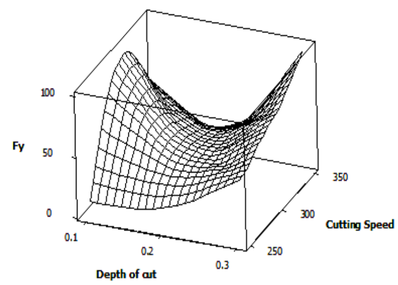

Figure 4 Surface plot of radial force (Fy) vs Cutting Speed and Depth of Cut

3.3 Analysis of Tangential Force (Fz)

ANOVA results are indicated in Table 6 for tangential force(Fz). With the ANOVA it was found that the cutting speed is prevailing factor affecting the tangential cutting force Fz. Figure 5 shows the main effect plot for fortangential force (Fz) for cutting speed, feed and depth of cut.

Table 6 ANOVA result for Tangential force (Fz)

Source	Sumof Squares (SS)	Degrees of Freedom (DOF)	Mean Sq. (MS)	F-Val. α=5 %	P-Val.
V	1984.4	2	992.2	1.25	0.444
f	375.0	2	187.5	0.24	0.809
d	1729.0	2	864.5	1.09	0.479
Error	1586.5	2	793.3	--	--
Total	5674.8	8	992.2	--	--

The feed rate has an insignificant effect on tangential force. Therefore, based on the S/N ratio and ANOVA analysis, the optimal cutting parameters for forces are the cutting speed at 250 m/min, the feed rate at 0.03mm/rev, and the depth of cut at 0.2mm.

The effect of cutting speed

It can be seen from Figure 5 the tangential force decreased as the cutting speed was increased, with different slopes.

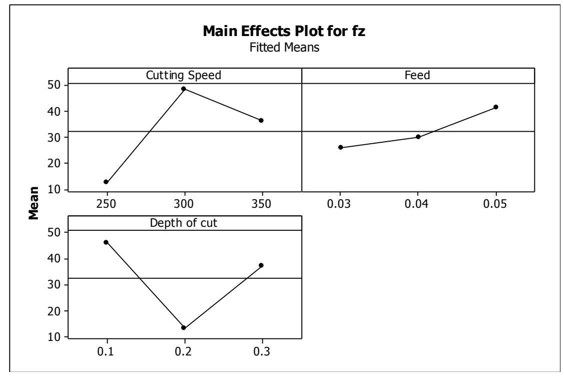

Figure 5 Main effect plot for tangential forceFz

The effect of feed rate

The effect of feed rate on cutting forces is shown in Figure 5. It can be noted that the increase in feed rate resulted in the increase in tangential forces. If the feed rate increases, the section of sheared chip increases because the metal resists rupture more and requires large efforts for chip removal.

The effect of depth of cut

Figure 5 signifies the influence of the depth of cut on the tangential forces. For the depth of 0.2 to 0.3 mm, we successively recorded the increase in components of the tangential cutting forces.

Figure 6 illustrate the surface plot of Fz, as cutting speed rate increases from 250 m/min to 300m/min, there is increase in tangential force, but for further increase in feed rate the tangential force decreases its magnitude.

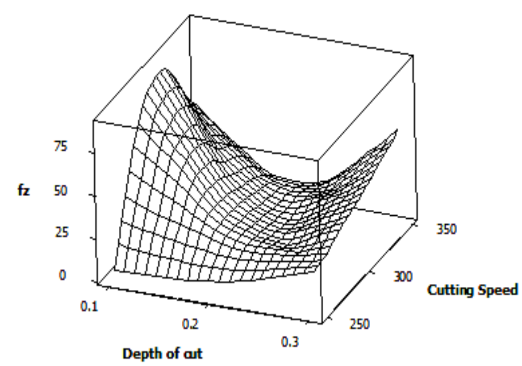

Figure 6 Surface plot of tangential force Fz vs Cutting Speed and Depth of Cut

It is observed from the surface plot that cutting speed and depth of cut are influencing effect on tangential cutting force. The three cutting force namely feed force Fx, radial force (Fy) and tangential force (Fz), were measured during hard turning of work steel of 48~50HR_c. Figure 7 shows the radial force was found to become the largest of the three force components at all cutting conditions.

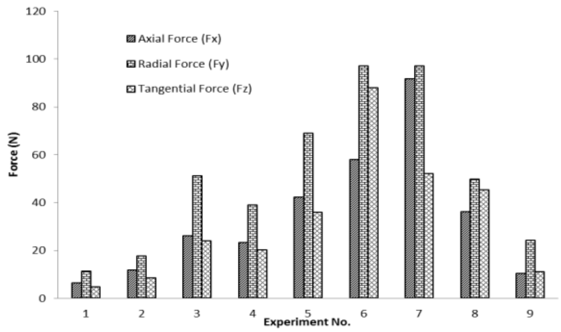

Figure 7 Results of three forces components for all cutting conditions tested

The cutting speed and depth of cut were the most significant factors under the radial force. The radial force showed to be the highest, because the depths of cut and the feed rates selected were significantly smaller than the insert nose radius (0.8 mm). As a result chip, the chip sectional area was very small, which contributes to lower cutting forces.

4. CONCLUSIONS

The present work reports a systematic experimental study on, the influence of turning parameters on cutting forces in hard turning of EN31 Steel with uncoated PCBN (MITSUBISHI) insert. From the analysis of experimental data and the identified predictive models, the following conclusions can be drawn.

The force relations occurring during hard turning significantly difference from the traditional cutting because the radial force component is the highest here.Thrust force is dominating compared to both others and that for the entire cutting system.

The measured values of the radial force were always the largest between the cutting forces and the cutting speed and cutting depth were the most significant factors under the radial force. With increasing of the cutting speed, the forces reduce due to the raised temperature in the cutting zone.

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