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Research Article

TOWARDS MINIMIZATION OF FOOT FORMATION OF EN25 STEEL FLATS

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Abstract: Foot formation in the workpiece during shaping operation is not favourable with early tool fracture, when a cutter exits the workpiece edge. Foot formation occurs due to gradual rotation of the positive shear plane to the negative shear plane about a pivot point. A number of tests in shaping operation is done in the present work on nickel chrome steel (En25) flats. Experiments are carried out in dry environment under different cutting velocities, rake angles and exit edge bevel angles to note the effect of foot formation. Experimental results are analyzed through ANOVA to find out the significance of the effect of cutting parameters and exit edge bevel angle to minimize the foot formation. It is observed foot formation that an exit edge bevel angle has the most significant effect. An exit edge bevel angle of 15^0 is recommended in orthogonal shaping operation when no foot formation is found.

Keywords: *Shaping, Edge beveling, Foot formation, Shear plane, ANOVA*

1. Introduction

A foot can be formed at the exit edge of a workpiece. It creates difficulty in producing precision components. A foot formation often accompanies with tool edge chipping. When the tool moves towards the exit edge in shaping operation, the chip may be separated along the negative shear plane resulting in a foot as reported by many researchers [1-4]. A number of studies have been made to understand this complex phenomenon. Hashimura et al. [2] observed that foot formation is usually occurred in machining of brittle materials during the occurrence of negative shear plane. For ductile materials, burrs are likely to form and/or with foot formation depending on machining conditions.

Pekelharing [5, 6] reported that tool fracture is occurred at the tool exit due to existence of a negative shear plane and chip formation mechanism changes near the exit edge of the workpiece. He also investigated the localized shear deformation along the fractured plane. Resulting fracture during burr formation along the negative shear plane was defined as a foot. Severe stresses are induced in the foot formation causing probable fracture in the tool. From the FEM analysis, it has been shown that negative shearing starts when tool position is about three times of the chip thickness inside the exit edge of the workpiece. Ramaraj et al. [7] did an experiment on foot formation and investigated that foot occurred when the positive shear plane changes suddenly to the negative shear plane rather than the gradual rotation. Some research works on foot formation was reported by Uchara [8], Pekelharing [5], van Luttervelt et al. [9], Saha and Das [10-16], and others. They observed that tools had failed due to continuous varying chip load in interrupted cutting and mechanical shocks at the entry side of the workpiece, besides that it is also failed due to foot formation during exit of the cutter. The tool may fail either by the gradual wear or catastrophic failure. Appropriate edge beveling of the workpiece reported by Saha and Das [17] can suppress foot formation.

The aim of the present work is to observe the influence of exit edge bevel angle of En25 steel flats on foot formation during orthogonal shaping operation; ANOVA is also done to validate experimental results and to find out the relatively significant process variables.

2. Experimental Investigation

2.1. Experimental conditions

Orthogonal shaping operation on a shaping machine with brazed HSS tipped tool is carried out to investigate the effect of exit edge beveling of En25 steel flats on foot formation. Details of the experimental set up and machining conditions are shown in Table 1. Experiments are done with two basic parameters, cutting velocity, Vc and top rake angle, α_0 varied as shown in Table 2. For each experiment set, tests are performed at five different exit edge bevel angles, θ (15°, 20°, 25°, 30° and 35°). At a cutting velocity of 15m/min, and rake angle of 0°, the experiment set is repeated twice of (experiment set no.3 and 4) to observe the repeatability.

After machining, test pieces are assessed for foot formation. Observed foot is classified following 10 point scale as reported by Saha and Das [17], where '0' stands for no observable foot, '1' as for negligible, and '9' indicates quite large foot formed. Detailed observation is shown in Table 2. The mechanism of foot formation is shown in Figure 1. Following the six experiments, it is seen that at 15° exit edge bevel angle, no foot formation occurs. At 22m/min cutting velocity and low rake angle of -3°, at 20° exit edge bevel angle, tendency of foot formation is seen. Gradual increase in foot formation occurs with the increase in edge bevel angle, θ from 20° to 35°. At a cutting velocity, Vc of 10 m/min, and rake angle, α_0 of -3°, substantially large foot formation is seen at exit edge bevel angle, θ of 35°. At the exit edge bevel angle of 15°, no foot formation is noted in all experiment. This may be due to reduced need of backup support material resulting in less chance of the formation of negative shear plane. Foot formation may be caused due to the presence of negative shear plane as reported by Ramaraj et al. [7]. At negative rake of -3^0, cutting force required is naturally larger than that at positive value of +5°, and tendency of foot formation is about higher on the whole (Table 2).

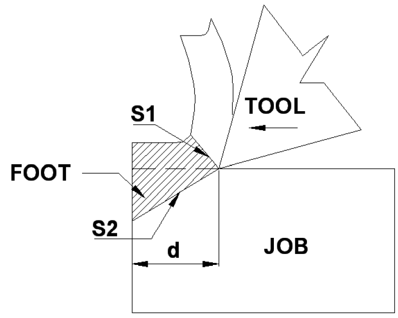

Figure 1. Foot formation mechanism [4]
(S1: Positive shear plane, S2: Negative shear plane)

Table 1. Experimental set up

Machine Tool	Shaping Machine, Pathak Industries, Howrah, Main Motor Power: 7.5 HP.
Cutting Tool	Brazed HSS tipped broad nose tool, Style of Tool: ISO 7 L.H
Tool Geometry	End cutting edge angle: 6°, Side cutting edge angle: 6°, End clearance angle: 3°, Back rake angle: 0°, Side clearance angle: 3°, Top rake angles: (i) 5° (ii) 0° (iii) -3°
Job Material	Nickel chrome steel (En25), Composition: C (0.32%), Mn (0.58%), Si (0.26%), Ni (2.55%), Cr (0.52%), Mo (0.31%), S (0.026 max), P (0.025% max)Hardness: 350 BHN
Job Size	90 mm X 65 mm X 2.5 mm
Exit edge bevel angle(°)	For each experiment set: 15, 20, 25, 30, 35
Machining Condition	Cutting velocity: Vc: 10, 15 and 22 m/min, Depth of cut (t): 0.05 mm, Width of cut: 7 mm, Environment: Dry, Type of machining: Orthogonal shaping

Table 2. Experimental results in Shaping

Experi-ment set No.	Cutting velocity, Vc (m/min)	Top rake angle (degree)	Qualitative amount of foot formed in 10 point scale at different exit edge bevel angles				
			15°	20°	25°	30°	35°
1	22	5	0	0	1	3	3
2	22	-3	0	1	3	3	4
3	15	0	0	0	3	3	4
4	15	0	0	0	3	3	4
5	10	5	0	0	1	3	3
6	10	-3	0	1	3	4	6

2.2. Results and discussion with ANOVA

Analysis of variance (ANOVA), is performed following Montgomery [18] on experimental results to observe the relative significance of different parameters, and to formulate the relationship between these parameters. The out put of the ANOVA is shown in Table 3. The ANOVA shows that system has high confidence level, and it has 0.000 level of significance. Table 4. shows different regression co-efficients. With these values, the regression equation is formed as given in Equation (1).

$$Qact= -2.984–0.02399\ Vc–0.135\ \alpha_0+0.217\ \theta \quad (1)$$

Table 3. ANOVA Table

Model	Sum of Squares	Degree of freedom (DOF)	Mean Square	F-value	Significance
Regression	76.851	3			
Residual	10.115	26	25.617	65.846	0.000
Total	86.967	29	0.389		

Predictors : Constant, Vc, θ and α_0, Dependent Variable : Qact

Table 4. Table showing Regression Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t-value	Significance
	Coefficient	Standard Error	Beta		
Constant	-2.984	0.554	-0.069	-5.387	0.000
Vc	-2.399E-02	0.023	-0.262	-1.037	0.309
α_0	-0.135	0.035	0.900	-3.918	0.001
θ	0.217	0.016		13.454	0.000

Table 4. shows that the variables, Qact has quite high confidence level as it has 0.000 level of significance, whereas Vc and α_0 have less confidence level having significance of 0.309 and 0.001. This signifies that exit edge bevel angle, θ has the maximum effect on foot formation where as orthogonal rake angle, α_0 and cutting velocity, Vc have the less effect on foot formation. Orthogonal rake, α_0 has higher significance than cutting velocity, Vc as the significance value of Vc is observed higher than that of α_0. therefore, exit edge bevel angle has to be optimized to have the least possibility of its occurrence of foot formation within the experimental domain.

3. Conclusions

From the present experimental investigation on shaping En25 steel flats under dry condition, following conclusions may be drawn:

- Beveling of the exit edge of the workpiece has substantial effect on reduction of foot formation.
- No foot formation is observed at 15° exit edge bevel under all machining conditions. It may be due to less need of backup support material at the beveled exit edge of the workpiece with gradual reduction in depth of cut needing gradually reducing cutting force.
- At the exit edge bevel angle of 35°, substantially large foot formation is seen that may lead to premature failure of the cutting tool.
- Analysis of variance (ANOVA) is done on the experiment to find out that exit edge bevel angle has the maximum influence on foot formation than cutting velocity and orthogonal rake angle where as orthogonal rake angle shows relatively higher influence than the cutting velocity on foot formation at the exit edge.

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