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Performance of Coated and Uncoated Inserts during Intermittent Cut Milling of AISI 1030 Steel

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Abstract

Knowledge of tool behaviour during intermittent cut machining of various work material is much required in order to improve the efficiency of the machining process. The tool-work impact and related effects of tool wear and surface roughness are often the subjects of interest. Even though, more work has been done to establish the relationship between cutting speed, tool wear and surface roughness during intermittent milling, there is no significant data available for AISI 1030 steel. To fill the gap, the machining of AISI 1030 steel using both coated and uncoated inserts were performed. Results were used to develop a linear regression model by which the relation between the machining parameters and the response were established. Results on tool wear patterns and wear mechanisms were compared between coated and uncoated inserts. Cyclic load on inserts and unstable temperature at cutting zone leads to flank wear and progressive chipping, which were the dominant failure modes observed. Coated inserts out performed uncoated inserts in terms of tool wear and surface roughness. The results also revealed that the feed rate was the dominant factor affecting surface roughness, whereas the cutting speed significantly contributes to the tool wear.

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Keywords: Intermittent milling, tool wear, surface roughness, regression modeling, ANOVA

1. Introduction

As the modern technology demands intricate machining profiles, intermittent cut machining is inevitable nowadays. The increased probability of tool wear and tool failure during intermittent cut creates the demand to analyze the performance of tools on various work materials. The cyclic load, impact pounding of tool and unstable tool-chip interface temperature are the acute factors to be analyzed during intermittent cut. High tool wear rate and poor surface finish during intermittent cut results in less productivity.

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Tool wear modes and mechanisms of AISI 1030 steel during intermittent milling were not addressed and therefore it is substantial to generate machining data for the same. The experimental work is to understand tool wear modes and patterns of TiN (Titanium Nitride) coated and uncoated cemented carbide inserts during intermittent cut. Tie bar plates made of AISI 1030 steel were selected for the experiment. Face milling along the bore of the tie bar plate (where the intermittent cut takes place) was conducted in many trials. Experiments was conducted according to the selected Taguchi's L9 Orthogonal array in a Vertical machining centre (VMC – Deckel Maho make), and finally the results were compared and validated.

NOMENCLATURE: V_c = cutting speed in m/min; f = feed rate in mm/min; d = depth of cut in mm; R_a = surface roughness in microns; V_b = tool wear in microns

2. Background

A cut in which one or more edges of the cutting tool are not in constant contact with the work piece surface is called as intermittent cut. The Prediction of the surface finish for specified tool geometry and cutting conditions has long been a matter of interest for finishing operations, and hence a number of models exist for the very simple cases but not for the intermittent cut operations. The entry of the tool and the exit of the tool are two critical states which has to be analyzed in detail during intermittent cut. Both entry and exit of the tool takes high impact pounding which is the major reason for the tool wear. Moreover, the constant cycle of engage and disengage of tools during intermittent cut leads to unstable tool-chip temperature. This is other critical factor to be analyzed. The tool entry and exit angle was investigated during intermittent turning and found that lower exit angle is beneficial for reducing the degree of tool fracture [1]. Tool failure rate is very high at exit of the tool rather the entry of the tool. Chamfered tool edges can reduce this type of tool failure rate occurring during exit of the tool [2]. Maximum and mean cutting temperatures are lower for intermittent milling than for continuous milling due to the effect of the cooling intervals. Thus the amplitude of the temperature variation and this variation likely plays a role in tool failure due to thermal cycling/shock [3]. Tool wear is found to be in increasing trend with an increase in frequency of intermittent cuts. The increased frequency of intermittent cuts leads to rapid tool wear. The predominant tool wear patterns were found to be adhesion and oxidation during intermittent cut [4], [5]. During intermittent milling of low alloy and carbon steels, at lower velocities tool failure is due to rake face pitting which is caused by the 'adhered' chip being thrown off the tool [6]. Multi layered coatings presumably have a deteriorated thermal conductivity, thus not providing sufficient relieve to the cutting edge of cemented carbides in intermittent cut machining [7]. The tool life and wear mechanism of TiN (Titanium Nitride) coated during intermittent cut were observed and found that cutting speed and feed rate had the most significant influence on tool wear and surface finish respectively [8]. The adhesion of work material increases the severity of cutting tool load which affects tool wear significantly [9]. The cutting forces increases with increased feed rate and depth of cut, AISI 1030 steel caused higher roughness values even at lower cutting speeds [10]. The time taken for the cutting edge of TiN-coated carbide tools to initiate cracking and fracturing is longer than that of uncoated cermet tools, particularly at higher cutting parameters [11]. The behaviour of surface roughness as cutting time elapses is very different from uncoated tools [12].

3. Experimental Details

A Vertical Machining Centre (Deckel Maho, Germany make) with a maximum rapid speed of 10000 rpm and cutting feed rate of 30000 mm/min was used for the experiment. Face mill cutter of 80 mm diameter, loaded with 7 inserts were used. The cutter has an approach angle of 75 degree, negative axial rake angle of four degree and a negative radius rake angle of 10 degree. The face mill cutter was positioned symmetrically to the bore of the work piece. Fig 1 shows the tie bar plate machining set up during the intermittent cut.

Fig. 1 Tie bar plate located in the machining set up

Surface roughness tester (MAHR make) is used for measuring the average surface roughness of the workpiece. All inserts were allowed a maximum flank wear (Vb) of 0.7 mm. Carl Zeiss Optical Microscope having magnification range of 500x is used for capturing tool wear images. Tie bar plate measuring width 220 mm and length 216 mm was subjected to experimentation. A scientific approach to the experiment is planned to adopt a factorial design. Taguchi L9 array has been selected for experiment, because they are more efficient than the experiments conducted taking factor at one time. Three input variables (cutting speed, feed and depth of cut) were selected with three levels as shown in Table 1. According to the selected L9 array as shown in Table 2 experiments were conducted and results were recorded. The rate of tool wear was compared between the inserts and the relations were established.

Table 1 L9 Orthogonal array

Trials	Input Variables			Coated insert Ravg Value in μm	Uncoated insert Ravg Value in μm	Coated insert tool wear Vb in μm	Un coated insert tool wear Vb in μm
	Vc	f	d				
T1	250	210	0.5	1.09	1.24	34	48
T2	250	480	0.7	1.24	1.32	67	88
T3	250	830	0.9	1.54	1.77	200	480
T4	350	210	0.7	0.98	1.09	45	67
T5	350	480	0.9	1.27	1.44	127	145
T6	350	830	0.5	1.49	1.59	33	42
T7	600	210	0.9	0.49	0.78	140	189
T8	600	480	0.5	0.89	0.95	30	37
T9	600	830	0.7	1.59	1.89	67	84

3.1 Analysis of Variance (ANOVA)

ANOVA was used to establish the significant factors influencing the machining process. The observed values of tool flank wear (Vb, mm) and surface roughness (Ra, mm) were used for determining the influential factors during the machining process. This analysis was carried out for significance level with confidence level of 90%. The sources with lesser P-value were considered to have a statistically significant contribution to the performance measures. The statistical ANOVA tables for all variances are shown in following tables (Table 2,3,4 and Table 5). From the table values, it is being inferred that the cutting speed is the most dominant factor which affects the tool wear and surface roughness. Feed rate is the next most dominant factor which affects the surface roughness.

Table 2: ANOVA: Ra (Coated) versus f

Source	DF	SS	MS	F	P
F	2	0.7153	0.3576	7.19	0.025
Error	6	0.2983	0.0497		
Total	8	1.0136			
S = 0.2230 R-Sq = 70.57% R-Sq(adj) = 60.76%					

Table 3: ANOVA: Vb (Coated) versus Vc

Source	DF	SS	MS	F	P
Vc	2	1593	796	0.18	0.842
Error	6	26945	4491		
Total	8	28538			
S = 67.01 R-Sq = 5.58% R-Sq(adj) = 0.00%					

Table 4: ANOVA: Ra (uncoated) versus f

Source	DF	SS	MS	F	P
F	2	0.8124	0.4062	8.52	0.018
Error	6	0.2861	0.0477		
Total	8	1.0985			
S = 0.2184 R-Sq = 73.95% R-Sq(adj) = 65.27%					

Table 5: ANOVA: Vb (uncoated) versus Vc

Source	DF	SS	MS	F	P
Vc	2	25313	12656	0.58	0.590
Error	6	131848	21975		
Total	8	157161			
S = 148.2 R-Sq = 16.11% R-Sq(adj) = 0.00%					

3.2 Modeling and regression analysis

Multiple linear regression models were developed for tool wear and surface roughness using Minitab software. The response variable is the tool wear and the surface roughness whereas the predictors are cutting speed, feed rate and depth of cut. They arrived regression equations were used to arrive the optimize input parameters.

Regression equation for coated insert

The regression equations are

$$Ra = 1.22 - 0.000497\,Vc + 0.000336f - 0.133d$$

$$Vb = -140 - 0.0410\,Vc + 0.0449f + 308d$$

Regression equation for Uncoated inserts

The regression equations are

$$Ra = 1.46 - 0.000746\,Vc + 0.000397f - 0.183d$$

$$Vb = -147 - 0.0133\,Vc + 0.0194f + 348d$$

4. Results and Discussion

The influence of selected input parameters on tool wear and surface roughness were determined for both coated and uncoated tool. During intermittent cut, with an increase in cutting speed, the frequency of tool entry and exit of the workpiece also got increased. Due to this, high impact load on tool edges occurs, which leads to rapid tool wear. This makes cutting speed even more important to the end of tool life. When the cutting edges used in the experiments were much more chipped than properly worn, this means that, the shock (high impact load) between the edge and workpiece during the entry of the tool was more important than the friction in causing the end of tool life. But at higher velocities, cutting edge gets chipped off due to stress reversal which is predominant for both coated and uncoated tools. Stress reversal due to cyclic load caused by the intermittent cut was well resisted by the TiN coated tool compared to uncoated tool. Abrasive wear was found during intermittent cut milling for both coated and uncoated tools. The major tool failure determinant is the location of initial impact on tool and its magnitude. The effect of feed was analyzed and found that lower cutting parameters, the effect of feed on tool wear were very minimal. Meanwhile, a considerable increase of surface roughness was noticed for both the tools with an increase in feed rate. The examination of machined surface quality was conducted after each trial and noticed that the feed rate was the most influential factor in determining the surface quality. The coated tool produced a lower surface roughness compared to uncoated. In common the surface roughness increased with the higher feed rates in all machining trial. Higher feed values leads to high temperature at the tool chip interface which leads to both adhesion (at lower cutting speeds) and abrasion (at higher cutting speeds) of tools. Due to these tool wears, the surface roughness was influenced accordingly. The major reason for that is the increased stress reversal at tool edges and high pounding of the tool edges due to the impact, with an increase of depth of cut.

4.1 Performance of coated insert with respect to surface roughness and tool wear

High surface finish values were obtained by coated inserts due to their less co-efficient of friction and low thermal conductivity of the coating. The effect of coating on tool produced better tool wear results in all cutting speeds while comparing to the uncoated tool. While the coating is still intact, the tool wear rate is very low, due to the high wear resistance of the coating. Coated tools performed better in surface roughness than the uncoated tool particularly with cutting speed above 350m/min. At the same time, the tool wear rate increased very sharply once the coating start to worn off and the work piece comes into direct contact with the substrate of the tool, which is much less resistant. At the cutting speed of 500 m/min, the coated tool performed excellently with less tool wear and minimum surface roughness, but the maximum flank wear occurred to the insert. Generally the coated inserts performed well at higher cutting speeds and moderate feed rate. The main effect analysis is used to study the trend of the effects of each of the factors. Main effect plot described that the cutting speed and feed are inversely related to surface roughness as shown in Fig 2. Fig 3 shows that the increase in cutting speed leads to higher tool wear rate. Minimum surface roughness is achieved at higher cutting speeds particularly above 350m/min. whereas, the tool wear increases with cutting speed increase. Feed rate is the significant factor in controlling the surface roughness.

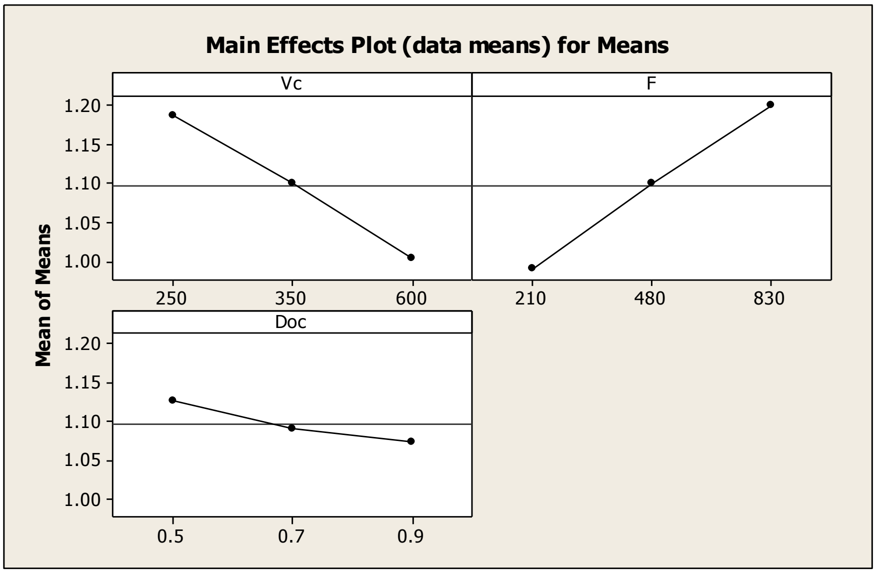

Fig. 2 Main Effects Plot (Ra vs Vc, f, d)

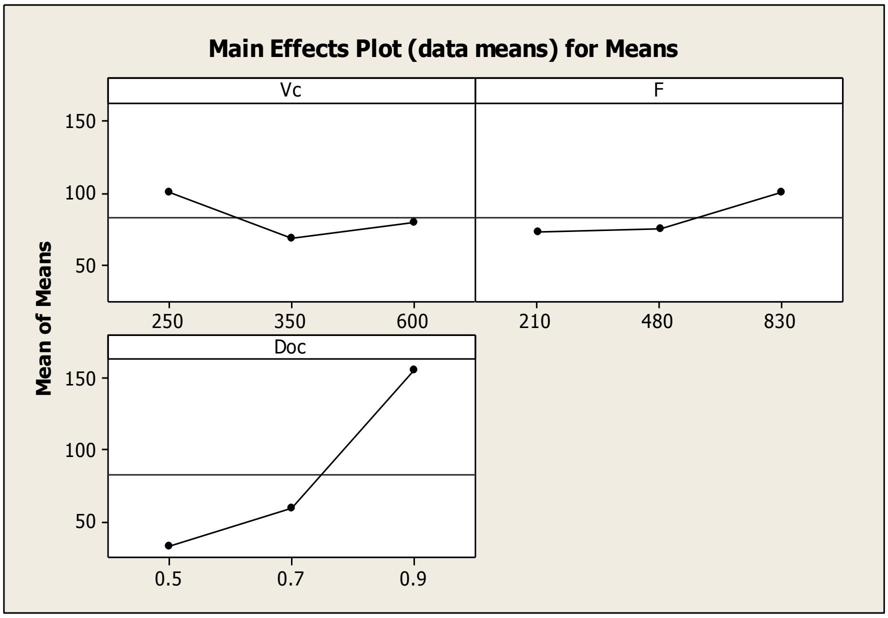

Fig. 3 Main Effects Plot (Vb vs Vc, f,d)

4.2 Performance of uncoated insert with respect to surface roughness and tool wear

At the cutting speed 350 m/min, uncoated inserts performed equally well to the coated inserts in terms of tool wear and surface roughness. Uncoated tool produced more or less values of surface finish and tool wear during the intermittent cut while comparing to the coated tool at the value of 350 m/min cutting speed. Uncoated inserts also got worn off at higher cutting speeds as like coated inserts but the tool wear rate is very high. Moderate cutting parameters are best suitable for the uncoated inserts in terms of tool life and cost. The main effect analysis is used to study the trend of the effects of each of the factors. The relations established in main effect plots are pretty similar to coated insert's main effect plots .The main effect plots for uncoated inserts were shown in Fig 3 and Fig 4 respectively.

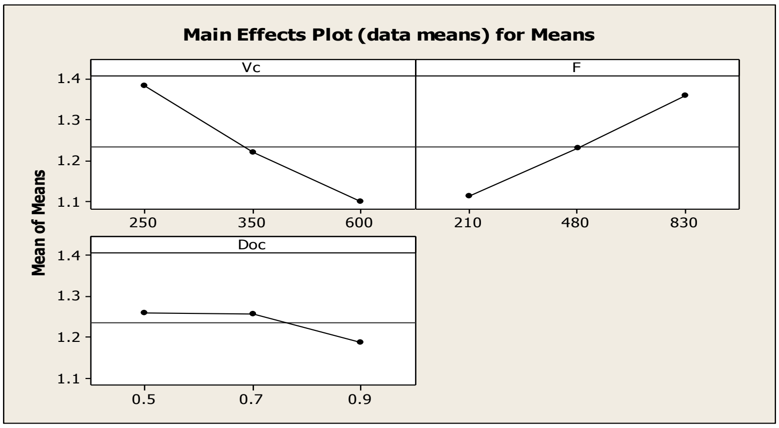

Fig. 3 Main effect plot (Ra vs Vc, f, d)

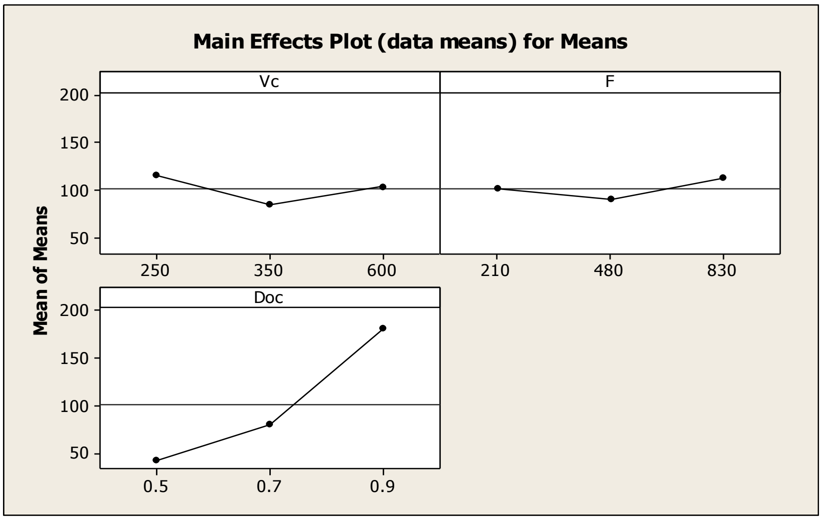

Fig. 4 Main effect plot (Vb vs Vc, f,d)

5. Conclusion

The relationship between the input and output parameters has been established for intermittent cut of AISI 1030 steel. To get the valid and objective conclusions, L9 orthogonal array has been adopted and a model has been proposed using the experimental data. Using regression analysis method an equation has been derived for tool wear and surface roughness. Based on the studies made, the following conclusions are drawn:

- High impact load during the tool engagement with workpiece during entry and exit creates to tool crack and failure.
- Variation in cutting speed has a predominant influence of tool life, regardless of whether there is variation in either feed rate or depth of cut.
- Coated tool produces better surface finish at higher cutting speeds, but the tool wear rate is very rapid. Dom inant tool wear is at flank face and the abrasion is the wear type.
- Uncoated inserts performs better at moderate rate cutting speeds comparing to coated inserts, but at higher cutting speeds the tool experienced maximum flank wear. The frequency of intermittent cut increases as the cutting speed increases which is the major reason for this.

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