Analysis of Tool Wear in End Milling of AISI 1018 Steel

Jatin Selmokar[1], P. Ravi Kumar[2]

Abstract— Tool wear increases cutting force, vibration and temperature in end milling and reduces surface finish of machined work piece. In this paper, a statistical model has been developed to predict the tool wear in terms of machining parameters such as spindle speed, feed rate and depth of cut. The experiments were conducted on AISI 1018 steel by high speed steel end mill cutter and tool wear was measured using tool maker's microscope. This paper studies the application of taguchi design to optimize tool wear in end milling. The direct and interaction effect of the machining parameters with tool wear were analyzed, which helped to select process parameters in order to reduce tool wear which ensured quality of milling.

Index Terms— AISI 1018 steel, Milling, Taguchi design, Tool maker's microscope, Tool wear

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1 INTRODUCTION

Machining which plays an important role in producing products is carried out everywhere. Milling is considered to be one of the three principal machining processes. Milling operation is the most widely used metal removing process in industry. The compatibility with all materials, its flexibility to use and the short lead times make milling one of the versatile operaions in any industry. The high friction between work piece and tool material leads to heat generation which causes tool wear and eventual failure of tool. Tool wear causes an increase in cutting forces, an increase in cutting temperatures and poor surface finish. These effects have adverse effects on the product to be produced. Many researchers have researched and have been continuing their research in the field of tool wear to solve this problem. Methods to decrease tool wear have been developed recently which have the benefits of low production cost, less wastage and higher production rate.

2 LITERATURE REVIEW

Pinaki Chakraborty [1] proposed a mixed effect model which led to the development of model describing tool wear progression during end milling of AISI 4340 steel with PVD TiAlN-TiN coated inserts under dry and semi dry machining conditions. The results show that the cutting speed has the most dominant effect on tool wear progression. The lowest tool wear was obtained at a cutting speed of 183m/min, feed rate of 0.10mm/rev under semi-dry cutting condition and highest tool wear was obtained at higher cutting speed of 229m/min.

In the study presented by Z. Q. Liu [2], wear patterns and mechanisms of cutting tools in high speed face milling were investigated. The wear performances of ceramic tool, coated carbide tool and PCBN tool are presented when machining of cast iron, tempered carbon steel and hardened carbon steel. The dominant wear patterns observed in this study were rake face wear, flank wear, chipping and breakage. S. Dolinsek [3] studied the different wear mechanisms present in high-speed end milling. A comparative analysis of wear types at the cutting edges of end mill cutters was done. It was found that cutting speed was not an influential factor on wear, but more likely wear was the consequence of high feed rate. H.Z. Li [4] presents an experimental study of tool wear propagation and cutting force variations in end milling of Inconel 718 with coated carbide inserts. The experimental study showed that flank wear was the predominant failure mode affecting tool life and performance of tool. It was observed that the flank wear propagation was more rapid in the up milling operation than in down milling operation. It was also observed that the tool wear propagation was the major reason for the gradual increase of mean peak force in successive cutting operations.

In the tests performed by P. Li [5] Central Composite Design (CCD) was adopted to study the relation between cutting conditions and the wear of micro endmill. A quadratic model was fitted to describe to performance of tool wear which was then compared to ANOVA results. The ANOVA analysis showed that the model gave good prediction of experimental values of tool wear. It was proved that the feed rate had a greater effect on tool wear of micro endmill. P. S. Sivasakthivel [6] developed a mathematical model to predict tool wear from machining parameters by response surface methodology in high speed end milling of AL 6063. Central Composite rotatable second order response surface methodology was employed to create a mathematical model and the acceptability of the model was verified using analysis of variance. The results showed that the helix angle was the most significant factor that contributed in reduction of tool wear which was in the range of 40° - 45°. Iqbal [7] studies about effect of cutting parameters in high speed milling of hardened AISI D2 under MQL environment. Experiments were conducted following Central Composite Rotational Design (CCRD) Method. Empir-

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ical models were built using experimental data for determining performance measures. The results obtained implied that increase in feed rate in hard milling process changes the dominant mode of tool damage from adhesion to chipping. SEM photographs and EDS analyses revealed that chipping and adhesion were the dominant tool damage mechanisms in majority of the experiments. Ahmed A. D. Sarhan [8] proposed a force model to monitor the end milling flank wear and work piece roughness. The tool wear is experimentally measured in an off-line manner using the toolmaker's microscope and the relationships of cutting force harmonics and tool wear magnitude is constructed and found to be comparable with the computer simulation results. P. Chockalingam [9] presents a study on effect of different coolant conditions on milling of AISI 304 stainless steel on surface roughness and tool wear. The experimental results show that the water-based emulsions gave better surface finish and lower cutting force followed by synthetic oil and compressed cold air. Water-based emulsion was derived to be the best coolant among synthetic oil and compressed cold air. Paolo Claudio Priarone [10] studied about the tool wear and surface roughness in milling of Gamma titanium aluminides. From the observation of the worn tools, it was assessed that the tool failed more often for corner wear, especially in the case of higher feed per tooth. The results show that the tool wear rate, in dry machining, increases as the feed rate and cutting speed increases. Lubrication condition was also assessed to be one of the factors strongly affecting tool wear mode. Ali Riza Motorcu [11] investigated the effects of cutting parameters on the surface roughness and tool life in dry milling of Inconel 718 super alloy. The types of wear and wear mechanisms were determined by examining the optical images of worn tools. The effective wear for both of the milling methods was free surface wear and nose wear. Wear increased linearly in both of the milling methods depending on the cutting time. S. Madhava Reddy [12] presents a study on the High speed end milling of Al-Si-Mg-Fe alloy for a cutting speed range of 1800 m/min and feed rates up to 5000 mm/min. The results obtained show that the cutting force has inverse relation to cutting speed which was due to the low friction coefficient at high cutting speeds. The main wear mechanisms observed were abrasive wear at the tool tip region and adhesive wear on the flank and rake faces. V. Shaikh [13] studies about tool wear during end milling of AISI 1018 steel using micro lubrication. It was stated that the cutting performance under micro lubrication is 5 times better under low cutting speed and feed rate combination as compared to high cutting conditions. The regression model clearly indicated that both the feed rate and cutting speed are significant factors responsible for tool wear. Higher tool life of 861 minutes was realized at a speed of 24 m/min and feed rate of 0.15 mm/rev. T. Leemet [14] presents a study in which the wear behaviour of 8 mm diameter end mills during dry machining of the HYDAX 25 construction steel was investigated. The study proposed two different methods to find out the tool wear occurring during the milling operation. S. Jozic [15] studies about the influence of cutting speed, feed per tooth and radial depth of cut on flank wear and surface roughness in end milling of hardened steel. Mathematical models were derived to analyze their influence of input parameters on flank wear and surface roughness. Flank wear and surface roughness were also measured by considering the volume of removed material for different cutting parameters.

3 EXPERIMENTAL METHODS

End mill experiments were performed on Sunrise sg-2 milling machine having a spindle power of 5HP and a maximum speed of 960 rpm. The objective of the experimental investigation was to determine influence of cutting parameters on tool wear, when end milling mild steel. AISI 1018 steel was used as workpiece material of dimensions 60x50x50 mm. AISI 1018 steel can be easily machined, welded and fabricated. AISI 1018 steel is a free machining grade that is often employed in high volume screw machine parts applications and is commonly employed in shafts, spindles, pins, rods, sprocket assemblies and an incredibly wide variety of component parts. End milling was carried out at different cutting parameters as shown in table 1. The cutting tool used in the experiment was 12 mm diameter solid stainless steel end mill having four flutes. Flank wear on flank was measured by Mitutoyo Toolmakers microscope as shown in figure.

TABLE 1
CUTTING CONDITIONS

Speed (RPM)	Feed (mm/min)	Depth of Cut (mm)
385	18	1
685	29	1.5
960	45	1.75

4 RESULTS AND DISCUSSIONS

4.1 Tool wear measurement

The measurement of tool wear was done with the help of a tool maker's microscope at a magnification of 50x.Tool wear on the cutter surfaces was observed in all the experimental conditions. No tool failure occurred in any condition. Flank wear was observed in the microscope. The primary reason of tool wear was due to the heat generation at the interface of tool and work piece. During Machining at cutting speed of 960 rpm and feed of 18 mm/min and depth of cut 1 mm, the tool wear had the highest rate in dry cutting. A significant amount of workpiece material was bounded to the flank and rake surfaces.

Fig. 1(a) to 1(i) represents tool wear images at different cutting conditions as per L9 orthogonal array. Fig. 1(j) represents image of tool wear of confirmation experiment.

TABLE 2
TOOL WEAR AT VARIOUS CUTTING SPEEDS, FEEDS, DEPTH OF CUT

Tool No.	Speed (RPM)	Feed (mm/ min)	Depth of Cut (mm)	Tool Wear (mm)
1	385	18	1	0.098
2	385	29	1.5	0.211
3	385	45	1.75	0.293
4	685	18	1	0.177
5	685	29	1.5	0.144
6	685	45	1.75	0.1
7	960	18	1	0.314
8	960	29	1.5	0.183
9	960	45	1.75	0.1956

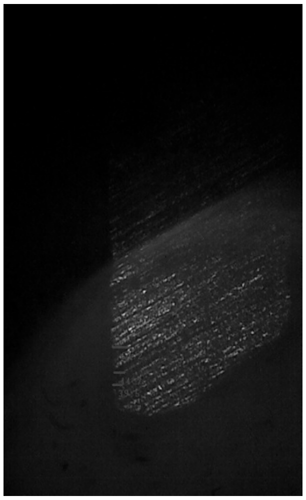
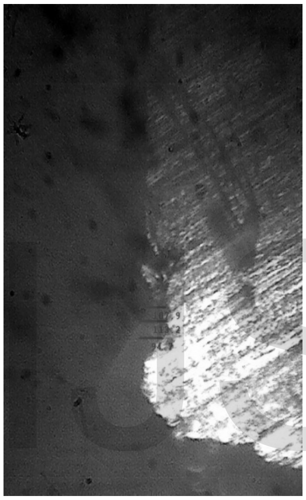


Fig. 1 (a)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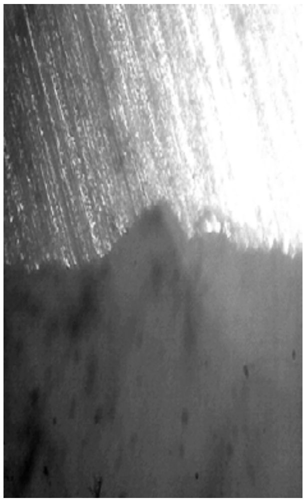
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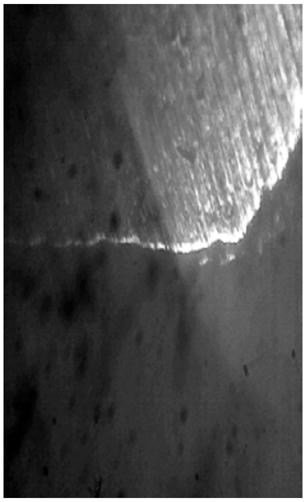
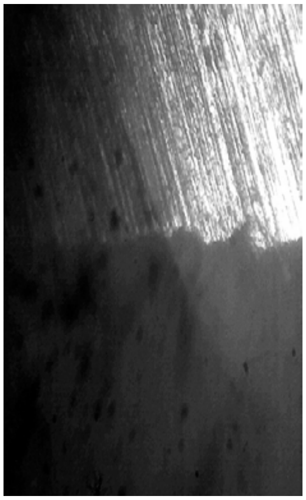


Fig. 1 (d)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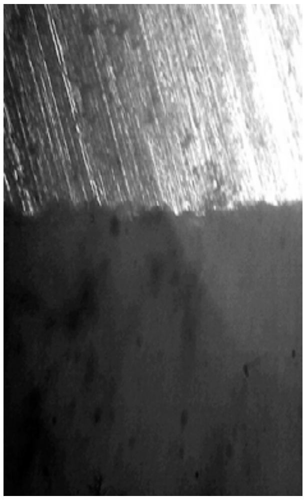
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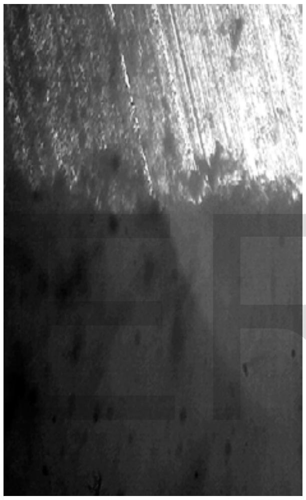
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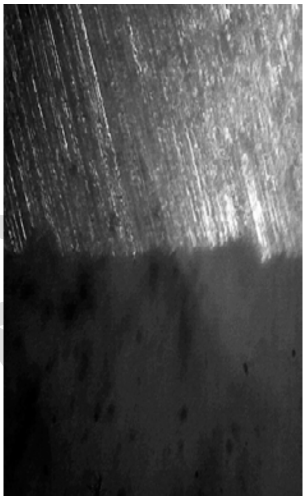
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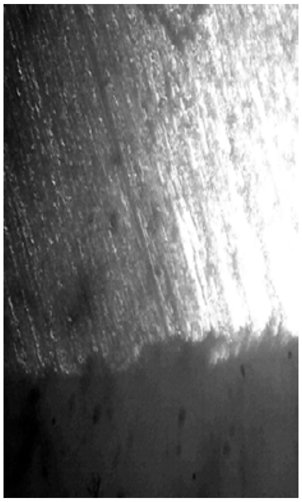
Fig. 1 (i)

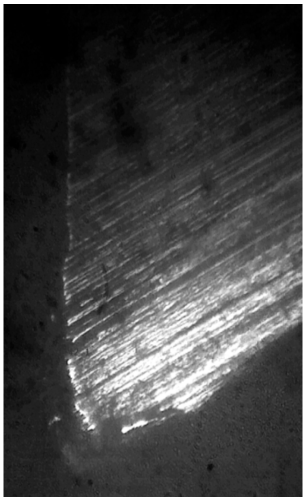
Fig. 1 (j)

Fig. 1 Tool wear at different cutting conditions

4.2 Orthogonal Array and Experimental Factors

Table 3 represents L9 orthogonal array considered in this experiment.

TABLE 3
L9 ORTHOGONAL ARRAY

Trial No.	Tool No.	Speed	Feed	Depth of Cut
1	1	1	1	1
2	2	1	2	2
3	3	1	3	3
4	4	2	1	1
5	5	2	2	2
6	6	2	3	3
7	7	3	1	1
8	8	3	2	2
9	9	3	3	3

4.3 Results of Taguchi Analysis

In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value for the output characteristic. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. Smaller is better S/N ratio was used in this study because less tool wear was desirable. Quality characteristic of the smaller is better is calculated in the following equation.

$$\eta = -10\log\left[1/n\left(\sum_{i-1}^{n} y_i^2\right)\right] \qquad (1)$$

In the equation (1) stated above n represents the number of experiments, y_i represents the required output parameter, η represents S/N ratio. Experiments are conducted in the order given by Taguchi method and tool wear values are measured and tabulated.

TABLE 4
TOOL WEAR VALUES AND S/N RATIOS

Trial No.	Tool No.	Speed	Feed	Depth of Cut	Tool Wear	S/N Ratio
1	1	1	1	1	0.098	20.1755
2	2	1	2	2	0.211	13.5144
3	3	1	3	3	0.293	10.6626
4	4	2	1	1	0.177	15.0405
5	5	2	2	2	0.144	16.8328
6	6	2	3	3	0.1	20.0000
7	7	3	1	1	0.314	10.0614
8	8	3	2	2	0.183	14.7510
9	9	3	3	3	0.196	14.1549

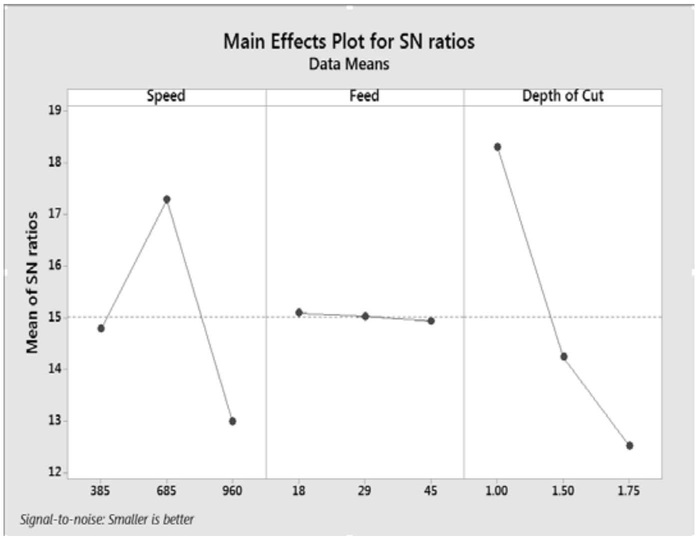

Fig. 2 Variation of S/N ratio wrt machining parameters

4.4 Predicted Values

According to Taguchi method, the optimum value of tool wear can be obtained with the 2nd speed, the 1st feed and the 1st depth of cut shown in Table 5 and 6.

TABLE 5
FACTORS LEVEL OF PREDICTIONS

Speed	Feed	Depth of cut
2	1	1

TABLE 6
OPTIMUM CONDITIONS OF CUTTING PARAMETERS

Speed (rpm)	Feed (mm/min)	Depth of cut (mm)
685	18	1

Predicted S/N ratio for the optimal machining paprameters stated in Table 5and 6 came to 20.6495. Tool wear corresponding to the predicted S/N ratio was equal to 0.0927.

4.5 Confirmation Experiment

A confirmation experiment was done to verify the results of Taguchi method. The parameters were taken as predicted by the Taguchi design. An inverse methodology was followed to get the statistical value of tool wear by considering the S/N ratio.

TABLE 7
COMPARISION OF STATISTICAL AND EXPERIMENTAL VALUES OF TOOL WEAR

Statistical Value of Tool wear	Experimental value of Tool wear	Error percentage
0.0927	0.0921	0.647

Experimental validation of results gave an error of 0.647%.

6 CONCLUSION

Based on the experimental finding following conclusions were made

- The machinability of AISI 1018 Steel when subjected to milling operation using high speed steel tool and the tool wear associated with it were investigated.
- The results indicated that the optimum tool wear was at medium cutting speed of 685 rpm. The selection of appropriate cutting conditions and the use of sharp cutting tools with adequate edge preparation are critical to achieve minimum tool wear.
- The optimal levels for the control factors were end mill cutter at spindle speed 685 rpm with feed rate 18 mm/rev and depth of cut 1 mm. Compared with the experiment values, the optimal tool wear of the 9 confirmation samples is 0.0921mm which was very close to the optimum value of tool wear 0.0927mm by Taguchi methodology.

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