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An Experimental Investigation and GA Optimization on Tool wear During Inconel 825 Turning with MQL

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Abstract

In machining of heat resistant super alloy tool wear and tool life is an important concern for economic cutting performance. This work investigate the machining performance during finish turning Inconel 825 super alloy using poly crystalline diamond (PCD) tool under two different machining environments (i.e., dry and minimum quantity lubricant (MQL)). Multiple regression equation has been developed and parameters were optimized using genetic algorithm (GA) for obtaining optimum combination parameters that gives minimum tool wear. MQL environment shows a significant reduction in tool wear compared with dry cutting condition. GA optimization provides optimum parameters for minimum tool wear and shows better convergent capability with minimum number of iterations. MQL under pulsed jet mode provides better operator's health and environmental friendliness.

Keywords: Inconel 825, Minimum quanity lubricant, Tool wear, Optimization, GA

1. INTRODUCTION

Inconel 825 is a nickel based hard – high heat resistance super alloy (38 HRC; 700°C –1000°C) finds applications in specialized areas such as nuclear, aerospace and marine industries [1,2]. The excellent toughness of the material results difficulty during machining and rises tool temperature, which results in tool wear and tool life is reduced. A number of researchers worldwide carryout research for improving different machining process for ensuring efficient and economic machining of these super alloys using different cutting tools. The production of components for desired value surface roughness with minimum tool wear is an important criterion in machining such materials using costly tool materials. The ISO standard 3685 dictates tool rejection criteria such that the machining to be discontinued if average flank wear (V_b>=0.4 mm, maximum flank wear ($V_{b(\max)}$>0.7mm), nose wear(V_C)>=0.5mm, or surface roughness (R_a)>0.6µm [3].

Recently, the concern on enviornmental effect leads to implementation of minimum quantity lubrication (MQL) during machining process. Thakur et. al., [4] attempted to optimize the MQL parameetrs to achieve minimum tool wear in turning Inconel 718 using WC-Co insert. They applied Taguchi signal to noise ratio for optimization and found that at low cutting speed and feed tool wear is minimum. Tamang and Chandrasekaran [5] developed an intelligent optimization technique for Inconel 825 turning process. They developed an artificial neural network (ANN) model for prediction of surface roughness, integrated with particle swarm optimization (PSO) approach to optimize the process parameters for desired surface roughness of jobs to be produced at minimum machining time. Kaynak [6] studied the machining performance of Inconel 718 in cryogenic machining and made comparison with MQL and dry condition. He considered *v*, *f*, *d* as input parameters and VB and Ra as performance characteristics. He found that at high cutting speed, tool wear is minimum and obtain good surface characteristics for CRYO and MQL. Astakov [7] investigated the influence of machining parameters on tool wear in turning of AL 610 alloy. The cutting speed is found most significant parameters which affect the tool wear followed by feed. Yazid et al., [8] also investigated the cutting parameters and machining conditions on surface roughness while turning Inconel 718 under dry and MQL conditions using PVD coated TiAIN carbide tool. They found that cutting speed from 90−120 m/min MQL turning provides better surface finish compared to dry turning.

In this work, an experimental investigation has been studied to find the effect of process parameters on tool wear during (MQL) machining. The process condition also compared with dry turning process. The process parameters optimized for obtaining minimum tool wear using popular global search optimization technique i.e., genetic algorithm (GA) for minimizing flank wear (V_b) of the tool during dry and MQL turning process.

2. EXPERIMENTAL WORKS

In this work, machining experiments were conducted in Inconel 825 using poly crystalline diamond (PCD) inserts during dry and MQL turning experiments. The work piece diameter and machining length was 55 mm and 110 mm respectively. The experiments were performed on the CNC lathe having Fanuc operating system (Model no. DX 200 4A) shown in Fig. 1.

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Fig. 1 CNC lathe used

Three parameters viz., cutting speed (*v*), feed rate (*f*) and depth of cut (*d*) are considered as process parameters and tool flan wear (V_b) was measured using Olympus STM6 optical microscope. In machining with MQL, the quantity of lubricant, delivery pressure at the nozzle and direction of application of cutting fluid are 60 ml/hr, 5 bar and 2 mm respectively kept constant during the experimental condition. In order to minimize possible number of experiments Box-Behnken design of experiments was employed and it is presented in Table 1 for both MQL and dry condition, effect of process parameters were studied and the efficiency of MQL machining process has been compared with dry turning process.

Table:1 Experimental results for MQL and Dry condition

Run order	*v*	*f*	*d*	*Vb (MQL)*	*Vb (Dry)*
1	150	0.10	0.5	138.12	154.12
2	50	0.16	0.3	123.12	138.24
3	50	0.16	0.7	99.89	101.69
4	50	0.10	0.5	55.66	115.12
5	50	0.20	0.5	92.79	130.56
6	100	0.10	0.3	122.03	143.34
7	150	0.16	0.7	245.33	315.12
8	100	0.16	0.5	104.24	107.00
9	100	0.16	0.5	104.24	107.00
10	150	0.16	0.3	121.51	129.60
11	100	0.20	0.3	145.21	157.62
12	100	0.20	0.7	138.52	184.56
13	100	0.16	0.5	104.24	107.00
14	100	0.10	0.7	129.32	174.89
15	150	0.20	0.5	129.66	169.89

3. DEVELOPMENT OF RSM PREDICTIVE MODEL

Response surface methodology (RSM) is the statistical and mathematical technique for obtaining input and output relationships. In the present work, a mathematical model is developed for correlating the effects of process parameters on tool wear in machining of Inconel 825 in dry and MQL conditions. The general quadratic RSM model is represented as follows:

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i x_i^2 + \sum_i \sum_j \beta_{ij} x_i x_j + \varepsilon, \tag{1}$$

where *y* is the performance output terms,$\beta_0, \beta_i, \beta_{ii}, \beta_{ij}$ is the regression coefficients and ε is the machining error.

Multiple regression equations are obtained for tool wear in dry and MQL turning process.

$$Vb_{dry} = 738 - 3.60v - 2401f - 1422d + 0.00766v^2 + 7718f^2 + 1024d^2 + 1.49vf + 5.15vd + 149fd \tag{2}$$

$$Vb_{MQL} = 269 - 0.86v + 1246f - 1116d + 0.00241v^2 - 1870f^2 + 864d^2 - 4.13vf + 3.41vd - 203fd \tag{3}$$

The predicted values of the tool wear give maximum and minimum error as 16% and 0.67 % for dry turning and 10% and 0.50% for MQL turning. The validation results for both dry and MQL turning is plotted in Fig. 2 and 3 respectively. The experimental results were analyzed and it shows that tool wear is minimum in turning with MQL. The application of pressurized lubricant in cutting zone reduces tool temperature and improves machining condition. The improvement in average percentage of error found more than 5% in comparison with dry turning process.

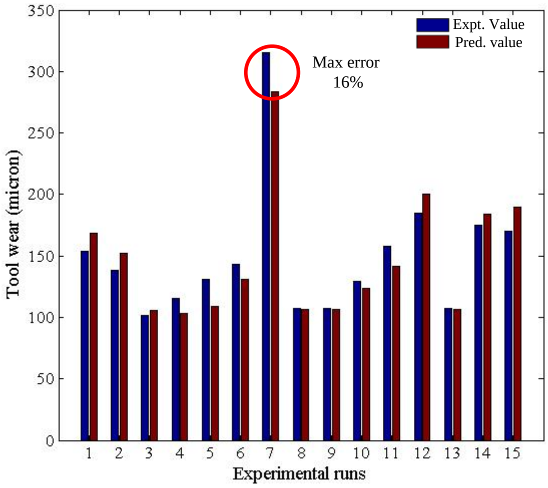

Fig. 2 Validation of dry turning

The contour plots for tool wear in MQL and dry condition is shown in Fig. 4 and 5. It shows that increase in *f* increases tool wear due to rubbing action between tool and workpiece. The generation of heat at flank side softens the edge leads to increased tool wear. The minimum tool wear is achieved at low feed, speed (50 m/min) and low depth of cut (0.50 mm) in both the machining condition.

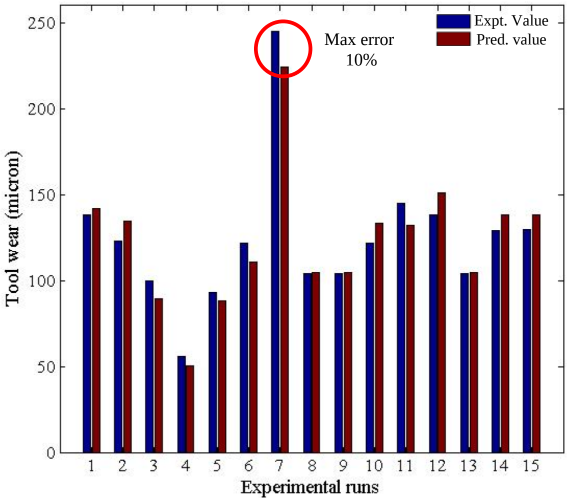

Fig. 3 Validation of MQL turning

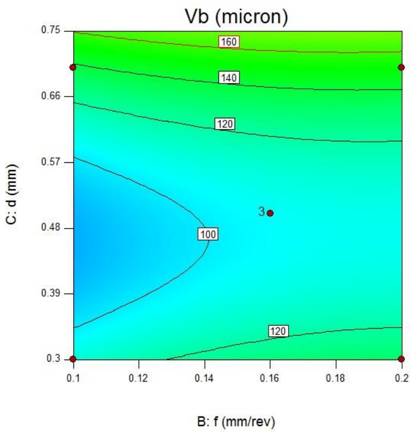

Fig.4 Tool wear Vs *f* and *d* in MQL machining

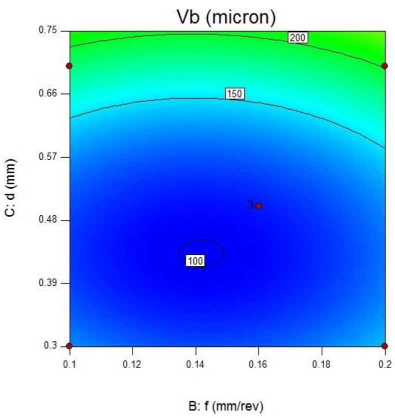

Fig. 5 Surface plot on tool wear Vs *f* and *d* in dry condition

4. OPTIMIZATION OF MACHINING PARAMETERS USING GA

Genetic algorithms are a popular random search algorithm commonly used for machining optimization. It works on the mechanics of natural selection and genetics [9]. The beauty of this algorithm is that it searches an optimal solution in the space of number of solutions, initialize from groups of points, rather than a single point. It uses the objective function to search the global optimal solutions. GA consists of three operations viz., reproduction, crossover and mutation. To formulate the optimization problem, the tool wear prediction model developed using regression model is selected.

4.1 Problem formulation

The optimization problem is formulated with the objective function being the multiple linear regression obtained from statistical modeling. The minimization function is subjected to variable bounds of the factors. The range of the level of each factor decides the upper and lower bounds of the variables.

$$Min.\_V_b$$

Subjected to:

$$50 \le v \le 150;\ 0.1 \le f \le 0.2;\ 0.3 \le d \le 0.7$$

For effective results in the optimization machining parameters, it is better to provide the actual values of the process parameters, and for this purpose experimental machining study was carried out. The following options are selected for formulating the problem:

Number of variables = 3; Population type = Double vector; Population = 100; Lower bound [50; 0.1; 0.3];Upper bound [150; 0.2; 0.7];

The problem is solved in GA using MATLAB tool box. The parametric study shows that the GA parameters that yield the best results are (i) crossover probability, p_c = 0.90, (ii) mutation probability, p_m = 0.25, (iii) population size = 100, (iv) maximum number of generations G = 50000. By using optimization toolbox, this study has tried several combinations of the set values for cutting conditions to present the best optimal results. The best combination of these values for cutting conditions will lead to the minimum tool wear.

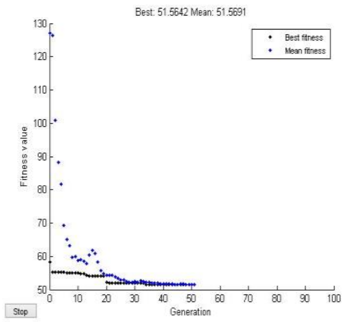

Fig. 2: Best fitness for MQL turning

The minimum value of fitness value (i.e., V_b (dry)=83.20 μm and V_b (MQL)=51.64 μm) is obtained at 52 and 51 generation in Matlab optimization tool box which are shown in Fig. 6 and Fig. 7 for MQL and dry conditions respectively. The optimum cutting condition for dry machining is *v*, *f*, *d*: 50.09 m/min, 0.145 mm/rev, 0.559 mm and for MQL is *v*, *f*, *d*: 54.75 m/min, 0.1 mm/rev, 0.549 mm respectively. The confirmation test was performed to validate GA optimization and the result shows good agreement with less error. This shows the effectiveness of the proposed algorithm.

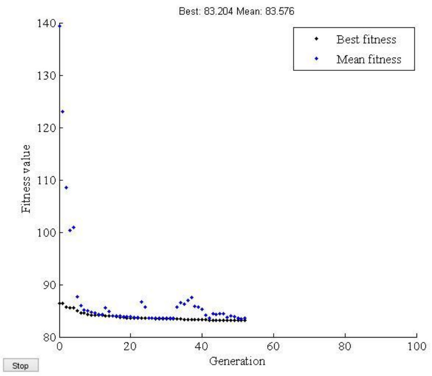

Fig. 3: Best fitness for DRY turning

5. CONCLUSIONS

In this work, an experimental investigation was carried out to compare/evaluate machining performance on dry and MQL machining environment during finish turning of Inconel 825 using PCD inserts. The following are important conclusions drawn.

1. The experimental results show a significant reduction in tool wear using MQL technique when compared to dry cutting. Reduced tool wear leads to better surface finish and improved tool life.Feed and depth of cut are found the most influencing parameters on the tool wear.
2. The issue concerned in optimization study is to obtain best combination of parameters that provide minimum tool wear, which is tried during experimental study. GA results shows minimum tool wear of 51.56 µm during MQL turning with cutting condition as v= 54.75 m/min, f = 0.1 mm/rev and d = 0.549 mm respectively which is below the experimental minimum. The confirmation experimental result is closer to GA that shows the effectiveness of the algorithm with better convergent capability.
3. MQL under pulsed jet mode found an effective approach for machining difficult to cut materials due to low thermal conductivity and lubrication capability. It also provides better operator’s health and environmental friendliness.

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