Optimization of Controllable Turning Parameters for High Speed Machining of Inconel 718 by Measurement of Surface Roughness

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Abstract— Dry machining is a machining process without the use of coolant, and it has become more popular for finishing process. Thus, it is especially crucial to select the machining parameters to obtain the desired surface roughness of machined Inconel 718. The experiments are planned as per the L27 orthogonal array with three levels defined for each of the factors in order to develop the knowledge base. The ANN model of surface roughness is developed with feed rate, cutting speed and depth of cut as process parameters. The necessary experimentation is carried out and the surface roughness values are recorded. A mathematical model is also developed using multiple linear regression, which gives relationship among the variables. The results are validated using Artificial Neural Network approach and Optimum values of input parameters are predicted.

Index Terms— Inconel 718, Orthogonal array, Artificial neural network (ANN), Regression Analysis, Optimization, Surface Roughness (Ra).

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1 INTRODUCTION

Super alloy Inconel 718 is one of the important alloys among the Nickel and Nickel-based alloy. Inconel 718 has found its niche in many industries, owing to its unique properties such as high oxidation resistance, corrosion resistance even at very high temperatures and retains a high mechanical strength under these conditions as well. Inconel 718 material is widely used in as aircraft engine parts, steam turbine, automotive sector etc. But due to peculiar characteristics such as lower thermal conductivity, work hardening, presence of abrasive Carbide particles, hardness, affinity to react with tool material etc. makes it difficult to machine. Hence, it is classified as ''Difficult-to-cut materials".

2 LITERATURE SURVEY

Madariage et al. [1] has presented a relevant literature on a comparative study of residual stress profiles on Inconel 718 induced by dry face turning. The main aim of his research work is to analyze qualitatively the uncertainty between experimental (X-ray diffraction and hole-drilling) and Numerical Methods. Residual stress profiles obtained experimentally in the present and the previous works for different cutting conditions show similar qualitative results, being more tractive near the surface and more compressive in the sub-surface layers. Accuracy discrepancy between numerical results and empirical measurements could be originated by at least two reasons: (I) the input data such as material properties and tribological data should be properly identified and (II) the traditional residual stress prediction model used in the present work is not able to reproduce all the complexity of machining.

Devillez et al. [2] has demonstrated that Dry Machining with a Coated Carbide tool leads to potentially acceptable surface quality with residual stresses and micro hardness values in the machining affected zone of the same order than those obtained in wet conditions when using the optimized cutting speed value; in addition, no severe micro structure alteration was depicted.

According to Schneider et al. [3], the difficulty of machining Inconel 718 resolves itself into two basic problems: short tool life and severe surface abuse of machined surface [4]. The cutting forces attain high values. Welding and adhesion of Nickel alloys onto the cutting tool frequently occur during machining causing severe notching as well as alteration of the tool rake face due to the consequent pull-out of the tool materials. The heat generation and the plastic deformation induced during machining affect the machined surface and induce quick tool wear [8]. The heat generated usually alters the microstructure of the alloy and induce residual tension stresses. Residual stresses are also produced by plastic deformation without heat, they are generally compression stresses. Heat and deformation generate cracks and micro structural changes, large micro hardness variations.

Itakura et al. [4], conducted dry turning experiments to identify clearly the tool wear mechanisms when a commonly used coated cemented Carbide tool cuts Inconel 718. During continuous cutting at a speed of 30 m/min, Inconel 718 adhered to the rake face of the major cutting edge and the adhering material became a stable built up edge protecting the face. For this reason, there was almost no rake wear but only

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Thomas Tavakoliet al. [5] has presented a literature review on study which “Investigates the High-Speed Machinability of this material under Laser-Assisted Machining (LAM) and Dry Conditions”. SEM analysis and microstructure examination of machined surfaces revealed the improvement in the surface integrity under LAM conditions. The main objectives of the study are (i) to optimize the laser-assisted high-speed finish turning of IN718, in terms of tool life, surface integrity, and productivity, and (ii) to assess the use of silicon nitride ceramic tools in Dry HSM to minimize the environmental impact and to reduce cost. Under these conditions, a significant drop in the cutting forces is achieved when compared to conventional machining. The surface finish is also improved by more than 25%, and the material removal rate is increased by approximately 800%.

3 EXPERIMENTAL DETAILS

Turning operations were carried out on ACE MICROMTIC SUPER JOBBER 500 LM CNC lathe. This lathe is provided with a high quality feed mechanism which maintains the set feed accurately.To examine the influence of machining parameters on process meters, experiments are carried out on Inconel 718 bar (of length 120mm and diameter of 30 mm) using TiN/TiAlN (PVD) coated tool inserts (Insert: SNMG 120408; Grade: TS2500).

Preliminary experiments were carried out to fix the limits of cutting speed for different cutting tool materials based on the available data for machining Inconel 718 from hand books and literature. The Cutting conditions selected for the experiments are shown in the table 1.According to Taguchi’s full factorial Design of Experiments an L27 3^3 Orthogonal Array was selected, Where number of factors are 3 (Cutting speed, Feed, Depth of cut), number of levels of each factor is 3 and number of experiments to be conducted are 27.

TABLE 1
EXPERIMENTAL CUTTING CONDITIONS

Tool Material	Cutting Speed (m/min)	Feed (mm/rev)	DOC (mm)	Cutting medium
TiN/TiAlN PVD coated	30,40,50	0.1,0.15,0.2	0.1,0.2,0.3	Dry

4 RESULTS AND DISCUSSION

The respective L27 OA is shown in the table 2 where Ra is found out experimentally for each setting and tabulated. The obtained experimental values are used as training data set where the experimental values are checked for their adequacy using validation datasets and statistical approaches. The graphs are plotted to know the effects of the control variables on the responses.

Regression model obtained using MINITAB software. While developing the above models, the correlation coefficient R^2 was taken as the fitness measure. Regression was continued till as close as to the maximum value of R^2 was obtained. R^2 was used as the fitness measure in order

TABLE 2
RESULTS/TRAINING DATA SET / VALIDATION DATA SET OF SURFACE ROUGHNESS USING PVD COATED TOOL

Sl. No	Speed (m/min)	Feed (mm/rev)	Doc (mm)	SR (µm)	
				Experimental Data Set	Validation Data Set
1	30	0.1	0.1	0.685	0.804609776
2	30	0.1	0.2	0.8	0.807647204
3	30	0.1	0.3	0.915	0.954339359
4	30	0.15	0.1	1.47	1.536522854
5	30	0.15	0.2	1.585	1.322007267
6	30	0.15	0.3	1.7	1.743651118
7	30	0.2	0.1	2.255	2.396937714
8	30	0.2	0.2	2.37	2.437435247
9	30	0.2	0.3	2.485	2.446840442
10	40	0.1	0.1	0.418	0.477731971
11	40	0.1	0.2	0.533	0.69808908
12	40	0.1	0.3	0.648	0.588783279
13	40	0.15	0.1	1.203	1.217873094
14	40	0.15	0.2	1.318	1.327342125
15	40	0.15	0.3	1.433	1.454605512
16	40	0.2	0.1	1.988	1.767914086
17	40	0.2	0.2	2.113	2.010790148
18	40	0.2	0.3	2.218	2.425338873
19	50	0.1	0.1	0.151	0.235433544
20	50	0.1	0.2	0.266	0.219182663
21	50	0.1	0.3	0.381	0.374819897
22	50	0.15	0.1	0.936	0.918310702
23	50	0.15	0.2	1.051	1.016615101
24	50	0.15	0.3	1.457	1.484483502
25	50	0.2	0.1	1.721	1.959906568
26	50	0.2	0.2	1.836	1.731768643
27	50	0.2	0.3	1.951	1.893298593

to check whether the fitted models actually describe the experimental data.The fitness measures for R_a have gradually improved with the number of generations and finally converged to 0.9943This shows that the model can explain the variation in the R_a up to the extent of 99.43%. On the basis of the high value of R^2 it can be said that the model are adequate in representing the process.

The regression model developed is shown below:

$$Ra = -0.2865 - 0.02508\ X1 + 15.711\ X2 + 1.312\ X3 \qquad (1)$$

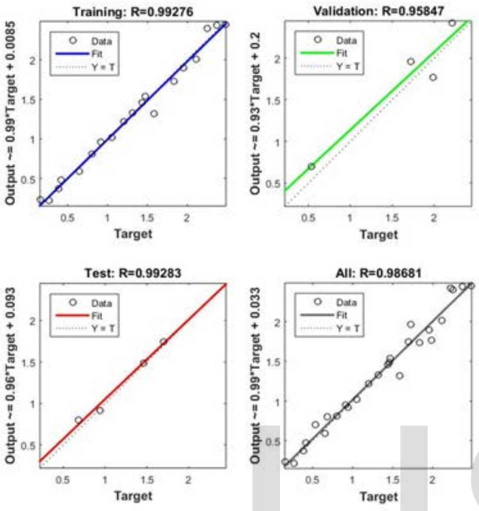

Fig. 3. Regression plot for ANN in MATLAB

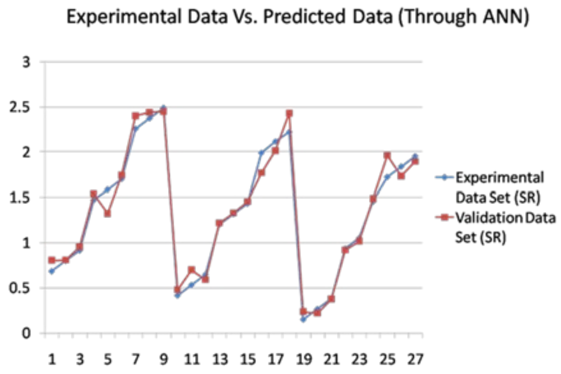

Fig. 4. Comparison of predicted values through ANN and experimental values of validation data set for R_a

Validation dataset: A comparison of the predicted models and the experimental values for the validation datasets of MRR and R_a are shown in figures 2 and 3 respectively. Very high values of R^2 for MRR and R_a of validation sets are obtained and found to be 0.9487 and 0.9659 respectively and these indicate that the developed models satisfactorily represent the outputs. The Regression plot for ANN is shown below.

Formulation of single - objective optimization problem: In the process of optimization, the aim is to maximize the quality. In a machining process, minimum $R_a$is to be achieved..Therefore, in the present work, the machining problem is formulated as a Single-objective optimization problem in which R_a is minimized subject to the feasible bounds of process control variables.The feasible bounds of the variables and the equations (2) are utilized for formulation of the optimization problem. The problem is stated as follows:

- **Minimum**

  Ra = -0.2865 - 0.02508 X1 + 15.711 X2 + 1.312 X3

  Subject to:

  - ➢ $30\ m/min \le X1 \le 50\ m/min$
  - ➢ $0.1\ mm/rev \le X2 \le 0.2\ mm/rev$
  - ➢ $0.1\ mm \le X3 \le 0.3\ mm$

TABLE 3
OPTIMAL SOLUTION

Optimal Setting	
Speed (X1)	50
Feed (X2)	0.1
Depth of Cut (X3)	0.1
Predicted SR (Y)	0.161593

TABLE 4
OPTIMAL SOLUTION

Top Five Alternative Optimum Solutions			
X1	X2	X3	Predicted Y
50	0.1	0.2	0.292759
40	0.1	0.1	0.412426
50	0.1	0.3	0.423926
40	0.1	0.2	0.543593
30	0.1	0.1	0.663259

5 CONCLUSION

The conclusions drawn from the research work are as follows:

- Mathematical model for Surface Roughness was developed using Regression Analysis. The proposed R_a formulations are empirical, based on experimental data. This is proved by the high values of the correlation coefficient, R^2(99.43 % for R_a) which was taken as the fitness measure in each case. Further, the developed model is tested for its accuracy and adequacy using Artificial Neural Network.

- The same Regression model was used to find the best or optimum solution (minimum in this case), where the optimum Ra was found to be 0.161593 micrometers that can be achieved with an optimum setting of speed 50m/min, feed 0.1 mm/rev and Depth of cut of 0.1 mm.

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