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Optimization of Process Parameters for Residual Stress in Hard Turning of EN 31 using Taguchi OA

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Abstract: In machining, though the cutting forces are released from the workpiece, still the stresses are induced in the body these stresses are called residual stresses. These stresses are independent of external loads. Residual stresses are equilibrium in nature. In the present research, the experiments have been carried out on the hardened Steel EN 31 using a fresh ceramet insert. The workpiece material was hardened to 60 HRC. The machining parameters considered for the optimisation are Speed, Nose radius, Feed and Depth of cut. Design of experiments is based on a Taguchi approach. Here L16 orthogonal array used to conduct the experiments. Process parameters varied over a viable space. X ray diffractometer is used to measure the residual stress. XRD is NDT for residual stress testing. NOVA performed to recognize the significance of the parameter.

Index Terms: Residual Stress, EN 31, X-Ray diffraction, ANOVA, Orthogonal Array.

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I. INTRODUCTION

Machining is a very wide term used to express the removal of material from raw material to provide the required shape. Turning is the material removal process, a single point cutting tool is used remove material from the raw material to give the required shape. The material removed in the form of a chip which slides on the face of the tool, known as tool rake face. In Hard turning machining process, turning of a hardened workpiece, within a span of 50–65 HRC, is done. In manufacturing industries, hard turning has an approaching towards final finishing operation [1].The residual stress generated after hard turning is compressive in nature. The effect of machining conditions on generated residual stress was investigated The main objective of study to find the depth residual stress [2]. Hard turning holds significant pledge for the upcoming manufacturing science it is a valuable means of increasing productivity. This is achieved because of the ease of use of superior hard tool materials i.e. PCBN & PCBC (polycrystalline cubic boron nitride and ceramics) and more rigid machine tools [3].

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The major cause of Fatigue failures and many other mechanical properties of hardened parts depend on the residual stresses developed during the machining processes. Residual stresses induced in hard turning processes may be classified as

- Differential plastic flow
- Differential cooling rates
- Phase transformations with volume changes etc.

It becomes essential to deem the quandary of residual stress as a compound problem including the stages of determination, analysis, and beneficial redistribution of residual stresses [4-5]. Residual stress in a workpiece remain stable and at K. equilibrium. It could damage to the performance of a workpiece or useful service life of workpiece. On the other hand, useful residual stresses can be introduced intentionally. Residual stresses are complex to envisage than the actual stress on which they place over. On the ground, it will become significant to have consistent technique to measure the magnitude of residual stresses. Different methods are available for the characterization of residual stress. Selection of the method it is significant to reflect on the sampling volume characteristic of the technique and the types of residual stress (type I, II, and III). Depending upon the depth affected by residual stress and the accuracy of the technique the measuring method will be selected. According to the different measuring methods broadly these are classified as destructive, non-destructive and semi-destructive [6-8].

II. LITERATURE SURVEY

Several investigations and experimentations have been analysed by the researchers reflecting the effect of process parameters on the residual stresses and surface integrity. The following subsections categorize their research conclusions. Varun Sharma et.al [9] performed experiments based on RSM to develop the arithmetical model for residual stress. Results of ANOVA discovered the feed rate has significantly effect on the residual stress generation. The considerable relations among machining conditions have also been presented in order to understand the thermo mechanical mechanism responsible for residual stress generation.G.kartheek [10] investigated the machining conditions of alloy. Titanium and aluminum based coating tools were used for the machining. In order to minimize the residual stress in turning the parameters are optimized. X-ray diffractometer used to measure the results. Gray rational analysis used for multi - objective optimisation. Inconel 718 alloy selected for experimentation.

From the study it was concluded that feed rate is significant parameter on the whole turning performance .Zhang Xuepinga et.al.[11] experimentally optimized process parameters for residual stress. Taguchi orthogonal array L9 used for the design of experiments. The turning parameters used is feed rate ,cutting speed, and DOC. The resulting residual stresses were tested by X-ray diffraction method.
Suha K Shihab [12] investigated the result of cutting parameters on surface integrity defined in terms of surface roughness and microhardness in dry hard turning process. Fredrik Gunnberg [13] the main objective of this study was to generalize the relation in cutting condition and residual stress. For turning PCBN inserts used. It was observed the residual stress is present 5 µm below the surface.
The investigation conclude the feed rate is major significant factor for the residual stress. From literature survey, it is concluded that, taguchi orthogonal array for design of experimentation is useful technique for parameters analysis. It is also helpful to be presumed that the investigation have been centered more around rake angle, nose radius. In addition, X-ray diffractometer is effective instrument to determine the residual stress.

III. EXPERIMENTATION DETAILS

Hard turning is a cost-effective, high productivity and flexible machining process for the ferrous metal workpiece.

Machining Conditions.

The workpiece material used in the study is the bar of EN 31.Furthe, the workpiece hardened to 55 Rockwell Hardness. To reduce discrepancies in conducted trials, the test pieces were machined on CNC turning center. Fig 1 shows the actual hard turning set up. The pieces after turning are shown in Fig.2. The International Standards nominated Cemented carbide turning tool inserts are CNMG coated. As the literature survey the machining parameters are selected. Their levels are mentioned Table I below shows.

B. Residual Stress.

The residual stress on surface can be analyzed along axial, circumferential, and radial direction. Current research, the residual stress measured in the radial direction. The residual stress for each measured with the help of X-Ray diffraction method as shown in Fig.3. Bragg's law i.e. the sine-square-psi ($\sin^2\psi$) technique used in X-ray deffracometer. In determining residual stress employing X-ray diffraction (XRD), the strain in the crystal lattice is measured. The residual stress measured in the radial direction. Actual count of grains and crystals that supply to the measurement based on the geometry of the X-ray beam and properties of the grain.

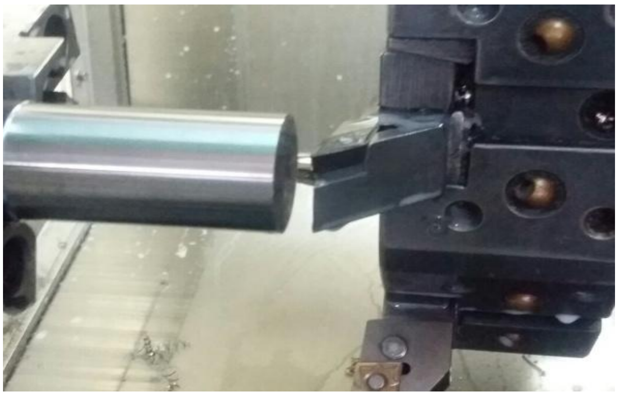

Fig.1.The actual setup used for experimentation

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X-ray diffractometre (XRD) is an entrenched, precise way to examine the residue stresses under surface.X-ray diffraction for residual stress measurements is widely available with portable testing.

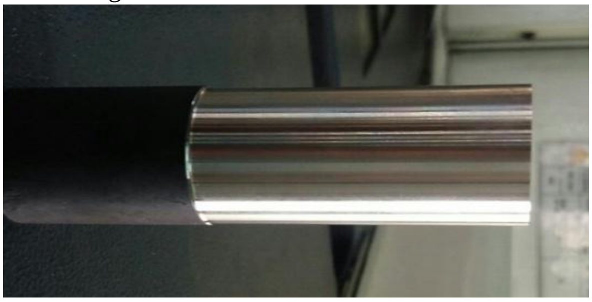

Fig.2. Turned Test Piece.

TABLE I
Hard Turning Parameters & Levels used for experimentation

Parameters	Levels			
Nose Radius	0.2	0.4	0.6	0.8
Speed	150	250	350	450
Feed	0.05	0.1	0.15	0.2
DOC	0.2	0.25	0.3	0.35

Basic principle of X-ray diffractometer technique is elastic strain testing depending on Bragg's law. Determination of the magnitude of residual stress depends on Hooke's law and elastic modulus (E) and Poisson's ratio (v).

C. Design of Experimentations.

In current research, in order to examine the significant turning parameters on the residual stress hard turning, a set of experimental runs was established using Taguchi L16 Orthogonal Array of the experiment as shown in Table II also shows the tested magnitude of residual stress. The principle of the hard turning study was to expand a widespread perceptive of the way of the machining condition on residual stress induced.

Fig.3 Measured Orientation.

Still, the turning parameters for residual stress required to be recognized therefore best possible arrangement of the turning experimentations can be resolute more correctly. That will be discussed using ANOVA.

TABLE II Orthogonal Array L16 [4^4]

Exp.No.	Nose Radius	Speed	Feed	DOC	Residual Stress
	mm	rpm	mm/rev	mm	MPa
1	0.2	150	0.05	0.2	67
2	0.2	250	0.1	0.25	8.5
3	0.2	350	0.15	0.3	99
4	0.2	450	0.2	0.35	174.3
5	0.4	150	0.1	0.3	15.3
6	0.4	250	0.05	0.35	280.9
7	0.4	350	0.2	0.2	216
8	0.4	450	0.15	0.25	297.1
9	0.6	150	0.15	0.35	263.9
10	0.6	250	0.2	0.3	319.3
11	0.6	350	0.05	0.25	604.5
12	0.6	450	0.1	0.2	548.5
13	0.8	150	0.2	0.25	213.2
14	0.8	250	0.15	0.2	68.7
15	0.8	350	0.1	0.35	74
16	0.8	450	0.05	0.3	539

IV. RESULTS AND DISCUSSION

A. ANOVA and Main Effect Plot

Analysis of variance is a one of leading and widly using technique to identify parameters. Also the allegedly degree of freedom in an each experiment can be determined. The frequency test (F-test) is availed in statistics to identify the significant effects of the parameters. Analysis of variance (ANOVA) as shown in table 3 was carried out to recognize factors which considerably influence the response variables.

This shows the result of ANOVA for residual stress process parameters. The analysis was carried out for a level of significance of 5%, i.e., for 95% a level of confidence.
Adj.SS is Adjusted Sum of Squares, Adj.MS is Adjusted Mean Squares

TABLE III
ANOVA

Source	DF	AdjSS	AdjMS	F-Value	P-Value
Nose Radius	3	249250	83083	12.88	0.032
Speed	3	137158	45719	7.09	0.071
Feed	3	98629	32876	5.09	0.107
DOC	3	14263	4754	0.74	0.596
Error	3	19358	6453		
Total	15	518658			

R-sq. is an arithmetical evaluation of closeness of the observations to the integral regression line. It is also known as the coefficient of determination. It is the entitlement of the response variable variation that is explained by a linear model. Table IV below gives the model summary.

TABLE IV
Model Summary

S	R-sq	R-sq (adj)	R-sq (pred)
80.3285	96.27%	81.34%	0.00%

B. Effect of Hard Turning Process Parameters.

The main effect plots of the hard turning parameters have been shown in Fig.3.It can be contingent that the depth of cut (DOC) is an inconsequential parameter for affecting the residual stress. Effect of the remaining three parameters is presented below.

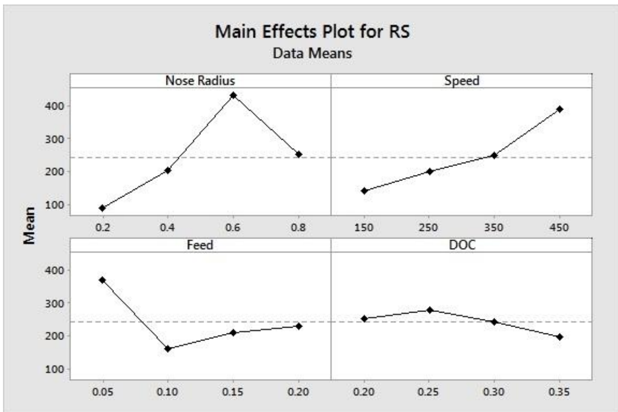

Fig.3 Main Effect Plot for Residual Stress means.

C. Response Table for Means.

Table V below shows the response for means. Use of response tables to select the best level for each factor. The delta and rank values to identify the factors that have the largest effect on each response characteristic. From the response table, it is observed that the nose radius is a major influencing factor followed by
speed and feed.

The depth of cut is the least effective parameter for residual stress.

TABLE V Response Table for Means

Level	Nose Radius	Speed	Feed	DOC
1	87.2	139.57	372.5	252.93
2	202.07	197.13	161.53	280.7
3	433.5	248.25	209.93	243.07
4	251.68	389.5	230.5	197.75
Delta	346.3	249.93	210.97	82.95
Rank	1	2	3	4

D. Regression Analysis

When a regression analysis is applying the least squares method to the investigational data in order to acquire the coefficients of this equation, the following equation is attained for residual stress.

Regression Equation

RS = 28 + 362 Nose Radius + 0.801 Speed - 755 Feed - 406 DOC

E. Parameters Optimization.

Fig.4 Optimisation Plot

From the above fig.4, it is clear that the optimized parameters for the residual stress are as listed below in table VI.

TABLE VI

Optimized Parameters.

Nose Radius	Speed	Feed	DOC
0.2	150	0.2	0.35

V. CONCLUSION

In the present experimentation work, the magnitude of residual stress of hard turned workpiece was determined. X-ray diffraction technique was used to measure the residual stress. EN31 material with 60 HRC hardened workpiece used for hard turning. The surface residual stresses along the radial direction were measured and analyzed. The influence hard turning parameters for the residual stress were revealed. Taguchi's L16 (4 4) OA design consisting of 16 sets of experimentations were selected to analyze the performance characteristics using ANOVA.

From the results obtained in this work, some of conclusions are listed below.

- As the nose radius increases, the residual stress at the surface lead to increase. Which shift towards more compressive residual stress. As the p-value is less than 0.05, it is a major influencing factor for residual stress.
- As the feed increases, residual stress at suface about to increase. There is a linearity trend observed between speed and residual stress. It is a major influencing factor followed by nose radius for residual stress.
- As the feed rate increases, the surface residual stress tends to be increased. Compressive deformation induced by higher feed rates.
- The depth of Cut is not an important factor for residual stress.

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