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Effect of Speed, Feed and Depth of Cut on Machining Induced Residual Stresses in Aisi 1045 Steel

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***Abstract:** Residual stress that are induced during machining of components plays a significant part in the endurance and life of the component. The magnitude and nature of the residual stresses have been of interest to many researchers across the globe. The present work involves methodology to find out the influence of factors on the residual stresses. The machining parameters were varied and the residual stresses were determined using non-destructive method, namely X-ray diffraction. Using statistical methods, the influence of the machining parameters was ascertained. This paper aims at investigating the residual stresses in AISI 1045 steel, induced due to milling. AISI 1045 steel was considered as it is a widely used material and its applications are innumerable. It was observed that speed and feed have significant influence on stresses left behind after the machining is completed. Using statistical techniques a mathematical model was developed which is further used to predict the residual stresses. The error percentage of the predicted values was less than 5%. The results obtained were promising and future work involves the optimization of the machining parameters.*

***Keywords:** Machining parameters, Mathematical modelling, Residual stresses, X-ray diffraction.*

I. INTRODUCTION

The life of a component depends on many factors like chemical, metallurgical and topological states. Majority of the components fail due to fatigue and the residual stresses within the component contribute to this fatigue failure [1]. Every component has to be machined to achieve its true shape and stresses are induced within the component during this process. The stresses that are left behind in the component after the removal of the machining forces, are termed as residual stresses [2]. The nature and the magnitude of such stresses play a significant role in the life of the component. In some cases, the residual stresses affect the performance of the component positively. For example, the compressive residual stresses reduce the corrosion rate whereas the tensile stresses increase the corrosion rate. Residual stresses have been the interest of many researchers [3, 4] over the years. Outeiro et al. [5] have performed analysis to determinethe effect of speed, feed and depth of cut on machining induced residual stresses in two difficult to machine materials. Dry turning was performed on Inconel 718 using both coated and uncoated carbide tool whereas only uncoated carbide tool was used to machine the stainless steel AISI 316L. A 3-D finite element model was developed for both the materials and the outcome obtained was compared with measured values. Destructive technique, namely hole drilling methodwas used to measure the residual stresses and found that higher residual stresses were induced with the uncoated tool. Ji et al. [6] have presented a model to determine the residual stresses that was generated while machining in minimum quantity lubrication (MQL) condition. The predicted residual stresses were a function of the material properties, geometry of the tool, cutting parameters and MQL machining parameters. Incorporating strain compatibility and kinematic hardening models, a thermo-mechanical model was made by coupling forces and temperature to determine the residual stresses, when machining was performed under lubricated conditions. They concluded that the cutting speed increases residual stresses in the direction of cutting and the same reduces the depth of the stresses and the feed rate increases the depth of penetration of machining-induced residual stress. A FE model was developed by Pu et al. [7] to simulate the residual stresses during cryogenic machining of AZ31B Alloy. This model established a relationship between the compressive residual stress and the corrosion resistance in Mg alloys. XRD technique was used to measure the residual stresses. Using experimental data, numerical simulations were performed after calibration for analysingthe effects of cooling methods (dry vs. cryogenic) and cutting edge radius on residual stresses. It was found that the residual stress distribution is deeply affected by the sequential cuts. They also suggested that a better consistency between the predicted and experimental residual stress during machining can be achieved if the initial residual stress into account in the finite element model..

Liang et al. [8] presented a model topredict the residual stresses developed in orthogonal cutting. The formulation of this model incorporated both the cutting forces and cutting temperatures to make use of these parameters to define the thermo-mechanical load experienced by the workpiece. Experiments have been performed on AISI 4340 and AISI 316L taking the cutting edge radius of the tool, speed and feed as the input parameters.

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The experimental results shows that the stressed region is increased by the roundness of the cutting edge. It was concluded that this model can be applied to a wide range of materials provided that the properties of the materials are available.

Kortabarria et al. [9] studied the residual stresses in Inconel 718 that are induced during machining. A 2D finite element model for orthogonal cutting with plane strain condition was used and a sensitivity analysis was performed to determine the influence of input data to the models on the predicted values of residual stresses.It was concluded that material constitutive law is the appropriateinput during prediction of residual stress.

Optimization of cutting parameters is an important aspect of machining. Zong et al. [10] developed a model to determine the residual stresses induced during diamond turning and optimize the cutting parameters. Orthogonal method, which is a combination design of the general rotary method was used to program all the simulations in order to consider the influence of the factors and the interactions on the residual stresses. In the turning of ductile materials,the research concluded that the rake angle has be to 15° and a clearance angle has to be 10° and nose radius of 100-300 nanometre. Similarly, an analytical model to predict the residual stress in AISI 4340 steel due to orthogonal machining is also presented by Agrawal [11]. Various studies have concluded that the tensile residual stress decreases with increase in edge radius and increases with the increase of cutting speed. In addition, the compressive residual stresses below the surface increases with the depth of cut. Investigations have been carried out on the residual stresses induced during orthogonal cutting in standard AISI 316L stainless steel and desulfurized steels [12]. The influence of speed, feed and depth of cut on residual stresses left behind were studied coupled with thermal and mechanical effects. X-Ray diffraction technique has been used to determine the depth profiles of residual stress. It has been observed that there has been a focus on influence of cutting parameters stresses which occur in machining operation. [13].

Hsueh et al. [14] summarized the analytical model and used the closed-form solutions for calculating the residual stresses in multilayered systems. And residual stresses resulting from the lattice and thermal mismatches were analyzed. While many researchers have tried to determine the value and magnitude of the stresses, many have attempted to model and predict the residual stresses [15, 16].Zhou et al. [17] used an analytical model for determining the residual stress based on thermal and mechanical load. The material that was used was Nickel-Aluminum Bronze alloy. The variable mechanical loading during machining was is taken into account. Also, the analytical model of stress field is analysedduring cutting theworkpiece which is a medial variable in the analysis of residual stress. The predictions obtained for cutting forces, cutting temperature and residual stresses from the model is compared with the FE method and experimental data. The authors concluded that the predictions of milling forces were in accordance with the experimental data. The performed experiment considered only the effect of the feed and cutting velocity stresses and found that the stresses left behind are mainly compressive on the surface. Both analytical and simulation models are available for the residual stress prediction [18-21] using various methods taking different parameters that affects the residual stresses. It has been observed that the researchers have mostly worked on orthogonal cutting processes rather than oblique cutting or very limited work is available in the oblique cutting process [22- 25].

Simulations have helped researchers to comprehend many details. Many simulation works has been carried out in the past to understand the residual stresses. Although researchers have made attempts to model and predict the residual stresses, researchers are under the impression that much needs to be done in this area as the results are not agreed unanimously.

In this paper, results of experiments and simulations that have been performed to study the effect of speed, depth of cut and feed on the stresses left behind after the machining process has been reported. A first order mathematical model in terms of machining parameters was developed for induced residual Stress using regression analysis. The predicted results and the experimental results of the residual stresses are correspondent to each other. The important aspect of this work is that care has been taken to ensure that only minimal residual stresses were present in the work piece before machining. The residual stresses were determined using XRD.

II. EXPERIMENTAL SETUP

The study of residual stress has been carried out on AISI 1045 steel. Machining of eight identical workpieces has been done taking different combinations of machining parameters rpm as inputs.

Any plastic deformation process is capable of producing residual stresses, so experimental procedure is performed after confirming that the samples were free of residual stresses. A standard specimen of size 24 X 24 X 4 mm, shown in Fig. 1. was taken for determining the stresses by non-destructive method. These specimen were obtained from a larger plate, machined to the required dimensions. Following the machining, the components were tested for residual stresses and it was observed that the stresses were in tolerable limits of ±5 MPa and compressive in nature. After ensuring that the components had minimal stresses, the components were machined according to an experimental design and the residual stresses were measured which is shown in Table 1.

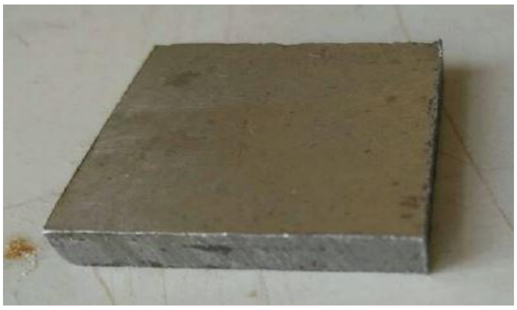

Fig. 1. AISI 1045 Specimen.

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Table 1. Experimental design and corresponding Responses.

Experiment Number	Speed (rpm)	Feed (mm/m)	Depth of cut (mm)	Residual Stresses (MPa)
1	355	40	0.2	-299.4
2	355	20	0.5	-391.3
3	500	40	0.3	-350.0
4	500	80	0.5	-170.0
5	500	20	0.2	-378.6
6	710	80	0.2	-222.3
7	710	20	0.3	-585.3
8	710	40	0.5	-374.9

III. STATISTICAL ANALYSIS

A linear regression was performed on the experimental data and a mathematical model was formulated using the results of regression analysis. Key parameters like R square and Adjusted R square of the regression statistics were observed to have high values which can be seen from Table 2, validating the regression analysis. This indicates that the obtained model is close to reality. The R square value is .89967 (89.9%) which shows that the regression analysis is close to the experimental data.

Table 2. Regression Statistics

Regression Statistics	
Multiple R	0.94850926
R Square	0.89966982
Adjusted R Square	0.82442219
Observations	8

The ANOVA analysis was performed to ascertain that the factors that were considered for the mathematical modelling are significant. The value of P is less than 0.005 indicating that the independent variables have a significant effect on the residual stress which is a dependent variable. The P-value of the first parameter (speed) is 0.049613, 2nd parameter (feed) is .004383, and the last parameter (depth of cut) is 0.939939 indicating that there is 4.9613%, .4383% and 93.9939% chance that the result (output) occurred only as a result of chance for each parameter respectively. These values are given in *Table 3*.

Table 3. ANOVA Results

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-340.74	90.37232887	-3.770	0.019596
Speed	-0.3763	0.135221607	-2.784	0.049613
Feed	4.7605	0.820173837	5.804	0.004383
D.O.C	-11.323	141.2101901	-0.080	0.939939

The value of Significance F as shown in *Table 4* is .01823 representing that there is 1.8% chance that the Regression output was merely a chance occurrence. The mathematical model developed using statistical techniques is given in Eq. (*1*)

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	98673.9	32891.3	11.956	0.018230
Residual	4	11004.0	2751.00		
Total	7	109677.9			

Residual Stress = -340.75-0.38 speed + 4.76 feed-11.32 depth of cut ……………………………………….(1)

IV. CONCLUSION

The mathematical model developed using the experimental results was able to predict the residual stress with a marginal error. The statistical values show that the model developed can replicate the actual experiments. It is observed that the surface had compressive residual stresses after machining. The present work was conducted on steel (AISI 1045) using a end mill cutter (6 flutes), future work involves changing other tool parameters like rake angle, number of flutes, changing the cutter diameter in addition to the machining parameters and determine the effect of such parameters on residual stresses. Use of modern algorithms such as genetic algorithm, simulated annealing, particle swarm etc..pose a good scope for optimization of the cutting parameters in the future.

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