

Modelling the effect of feed rate on residual stresses induced due to milling using experimental and numerical methods

Prakash Marimuthu¹, Benjamin Durakovic², Saketh Ram Kunda¹

¹ Department of Mechanical Engineering, Amrita Vishwa Vidyapeetham, Amrita School of Engineering, Bengaluru, India

² Industrial Engineering, International University of Sarajevo, Bosnia

ABSTRACT

The surface integrity of any manufactured product produced in machining process has proved to have a significant impact on the performance of the product. Many parameters influence the integrity of the surface, few of which are microstructure of the material, surface roughness, residual stresses etc. Out of which the present work focuses on the residual stress of the machining, which majorly effects the fatigue strength of the product. Understanding the significance of residual stresses in machining, and influencing it using three basic parameters: feed, cutting speed and depth of cut to increase the products performance and life by optimizing these measures to best possible combination. It is done using both experimental and numerical methods and authors have compared the numerical and experimental values. For experimental purposes AISI 1045 steel was used and the residual stresses measurement was done using X-ray diffraction method.

Keywords: Residual stresses, surface integrity, X-ray diffraction, AISI 1045 steel

Corresponding Author:

Prakash Marimuthu K.
Department of Mechanical Engineering,
Amrita School of Engineering,
Amrita Vishwa Vidyapeetham, Bengaluru, India
E-mail: k_prakash@blr.amrita.edu

1. Introduction

To manufacture any product, machining is a very important and crucial process. It determines the quality and the life of the product. There are several methods for machining any product. The quality of the product is basically recognized by two factors, one is safety and the other is reliability. The quality varies upon the machining operation preferred and executed. This machining process influences the surface integrity of the product or component. Surface integrity can be understood in three main fields: surface roughness, transformations of micro-structures and residual stresses. One way to judge the surface quality is surface roughness. However, residual stresses are not that evident like roughness, though play a decisive role in the performance of the component. It is a key factor, which influences the fatigue life, corrosion resistance, dimensional accuracy, etc. These residual stresses are majorly evaluated for turning and grinding operations all over the world. These stresses are found directly related to the cutting parameters like cutting speed, feed, and depth of cut. Moreover, there is no much attention given to understand the formation of residual stresses in milling with important machining phenomena like the dynamic cutting forces and cutting temperature.

In the present work investigation is done on the influence of cutting parameters (specifically feed) on the formation of residual stresses while milling a slot on mild steel using both experimental and numerical methods.

2. Literature review

Due to the several factors residual stresses are induced within the part or component. Often stresses are developed and retained due to non-uniform cooling of the outer and the inner surface of the component. Residual stresses in metals are also caused due to the non-uniform plastic deformation throughout the cross-section of the part to be deformed. In this context, the focus is on modelling of residual stresses and parameters which influence the stresses using mathematical methods and testifying it with experimenting techniques. There has been many research's goings on understanding the induced residual stresses in machining. The research work in residual stresses previously dealt with the experimental tests investigating the behavior of residual stresses.

Although major work was in predicting residual stresses in orthogonal cutting operation by using mathematical models and validating it with experiments. The residual stress formation mechanism changes with many parameters like cutting condition, tool, work piece material, process parameters like the cutting speed, lubrication, tool rake angle, tool and work piece combination, feed rate, amount of material being removed [1]. Apart from these, few cutting conditions like temperature and cutting forces also affect the residual stress distribution. The results through this research have proved that residual stresses increase with increase in cutting parameters, uncut chip thickness and radius of cutting tool edge. But, out of these parameters, the chip thickness before being cut seems to influence the residual stresses the most. The research has extended in the mathematical modelling (FEM) of residual stresses and comparing it with the experimental results. There were many scholars who like Guo and Liu who have proved the influence of cutting parameters in the distribution of residual stresses in orthogonal cutting of steels [2]. In Wiesner's approach, he showed experimentally that high tensile stresses up to 700 MPa were induced in the AISI 304 steel. He has experimentally validated it using X-Ray diffraction method and proposed a FE model and presented the effect of temperature and mechanical loads on the residual stresses [3]. Further research by Guo and Liu proved that the residual stresses will turn compressive with sequential cuts on the material. They showed that, with decreasing the thickness of the chip before cutting, the residual stresses are more compressive type and it is concluded that it is appropriate to have a favorable finishing cut conditions for better residual stress distribution.

The present work focusses on developing a numerical model which will enable researchers to determine the residual stresses in machining (milling) and compare the same with experimental values. Numerical simulations help the researchers to understand the structural, flow behavior in a system [4–6]. The developed model is 3d oblique cutting unlike many researches which are orthogonal.

3. Research method

The work pieces of dimension $80 \times 50 \times 6$ mm were prepared from AISI 1045 steel plate. This was done to accommodate the work-piece in the XRD machine. The tool used for the milling process is an end mill of diameter 6 mm with 4 flutes. The tool is made of tungsten carbide material for its rigid characteristics while cutting. The machining was done using a vertical milling machine. The Residual stresses measurement was done using a non-destructive method X-Ray Diffraction method.

To identify significant process parameters on the residual stress, the general linear model of ANOVA [1] with 0.95 confidence interval is applied.

3.1. Finite element model

There has been more research on computational models of simulating the residual stresses using different approaches. Few authors have revealed experimentally, that high tensile stress observed externally, and then a peak of compression below in a turning operation of AISI316L stainless steel. Analytical models [9–13] have been proposed which made the calculation of residual stresses much easier. Also, there are other works on numerical Lagrangian formulation for removal of material [3, 10, 14, 15]. There are different models used based on the effecting parameters like the plain strain finite element model by Shih and Mishra developed a model based on finite element method to predict residual stresses induced because of a moving heat source.

The present work involves the modelling of residual stress numerically for a milling operation and comparing the test results of the experiment with numerical values. The machining induced residual stresses play contradicting roles at different situations of time. Investigating the residual stress behavior by modelling using finite element modelling will help the researchers to have a better understanding of the formation of stresses and the stresses that are left behind after the machining load is removed.

Mathematical modelling helps us to provide a link between the input parameters (independent variables) and the output variables (dependent variables). The experimental way of determining the stresses that are left behind in the parts after machining as explained in the previous section is an expensive method and effort is needed to make sure that the results obtained are accurate [16–21]. A lot depends on the specimen preparation and measurement; hence a mathematical model will help us to predict the residual stresses for a particular machining condition. This will help in the reduction of time spent in the conduction of experiments and it will be cost effective.

In the present work it is observed that, for the purpose of simulating the residual stresses that are induced during the machining process, the combined use of Johnson-Cook material model and Johnson-Cook damage model is very effective.

3.2. Material model

Material modelling is one of the key steps in the simulation of the metal cutting processes. Like any other finite element analysis, the basic material properties required for the analysis is fed. In addition to that the material properties required to simulated large deformation process is also fed to the software. In the machining process the chip is separated from the parent material. In other words, the material removal happens in the form of chips. To capture the shearing of the material and formation of the chips Johnson-Cook material model along with Johnson-Cook damage model is used in tandem so that the metal cutting process can be simulated [22].

3.3. Damage model

For the material removal to happen damage initiation and damage evolution are parameters of importance. Johnson-Cook damage criterion along with Johnson-Cook material model is used in the present research work.

3.4. Model

The Finite element was done using commercially available Abaqus software. The tool and the work piece are assembled as shown in Figure 1. An explicit dynamic analysis was done and the residual stresses were predicted using the model.

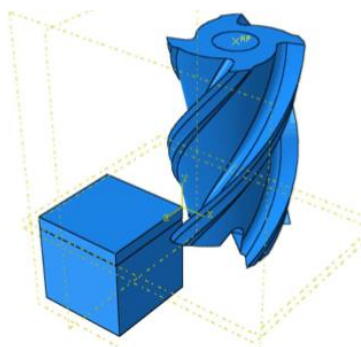


Figure 1. Assembly view of work piece and the tool

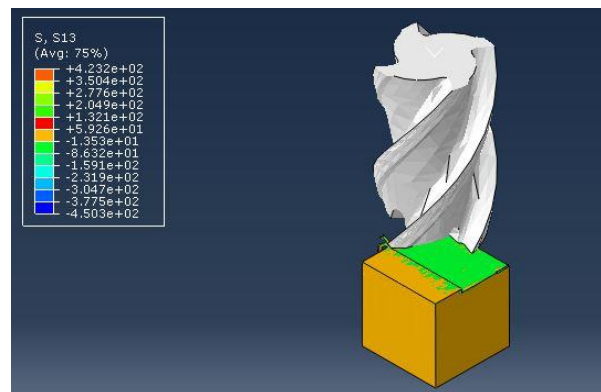


Figure 2. Residual stresses distribution

The model was assigned with the properties of AISI 1045 steel for work piece and a rigid tool was considered for the analysis. Stresses that were induced during the machining was determined. Figure 2 shows the distribution of residual stresses for one of the cutting conditions. Cutting force variation is depicted in Figure 3.

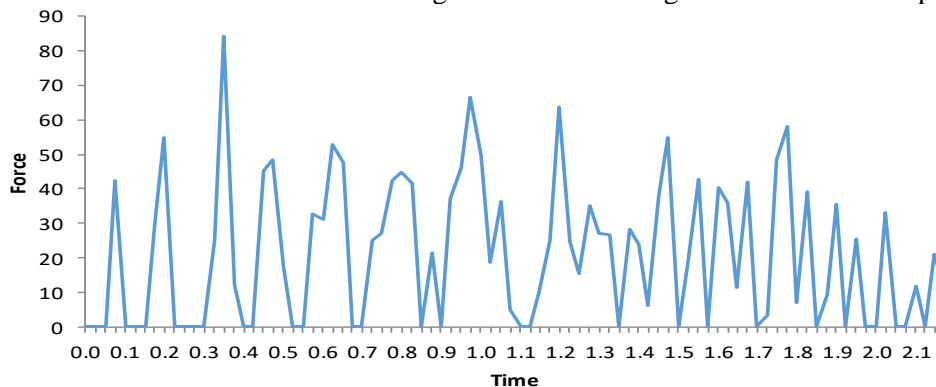


Figure 3. Time vs. cutting forces for 160mm/min feed rate

The following table shows the residual stress values for at conditions.

Table 1. Machining induced stresses measured using FE model for different cutting condition

S.No.	Feed rate (mm/min)	Residual stress (MPa)
1	40	-162.864
2	80	-169.681
3	100	-261.009
4	125	-245.782
5	160	-277.654

Speed and depth of cut was kept constant, and the feed rate was varied in the FE analysis whose results are tabulated in Table 2.

Table 2. Residual stresses value for different experimental conditions.

S. No.	Feed (mm/min)	Experimental Residual stress (MPa)
1	40	-279.9 ± 10.9
2	80	-390.6 ± 18.7
3	100	-269.9 ± 11.1
4	125	-239.3 ± 10.3
5	160	-221.7 ± 10.4

From the measured values, it is understood that the compressive stress is more due to milling performed with less feed rate. The variation between the experimental work and the FE analysis is shown in Figure 4.

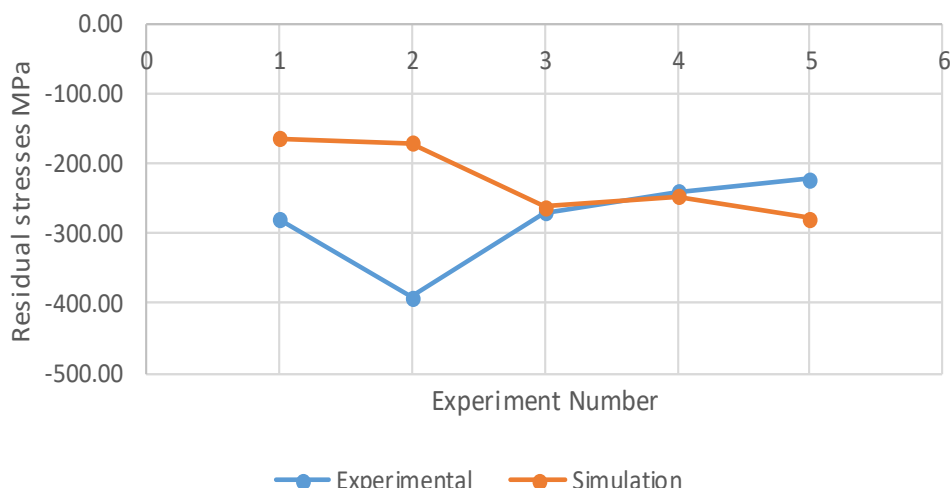


Figure 4. Comparison of experimental and simulation results

4. Conclusion

An experimental method is used to determine the influence of process parameters on the residual stress in material after machining. Speed, Feed and Depth of cut are the parameters, that is the machining parameters considered in this study. A 3D model was developed to predict the residual stresses that are induced due to machining. Experimentally the residual stresses were determined for different cutting conditions. For the same cutting conditions, the FE model was used to compare with the experimental values. It was observed that the FE model was able to predict the residual stresses with a very good accuracy and that the feed rate had significant effect on the machining induced residual stresses.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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