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Effect of Cutting Conditions on the Residual Stresses Induced by Milling of AISI 1045 Steel

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Abstract: The nature of residual stresses caused by machining processes has been relevant to the study of component performance for decades. The concept that cutting parameters affect the magnitude and nature of residual stress is well known. In order to reduce the residual stresses on a machined surface, it is important to identify the extent of the effect of cutting conditions. This paper presents the effect of depth of cut and tool speed on milling induced residual stresses. Speed and depth of cut were varied when milling several AISI 1045 Steel specimens. Stresses were measured with the X-ray diffraction method and corroborated with mathematical modelling on an FEA software. A relationship between tool speed and residual stress, and depth of cut and residual stress was thus obtained.

Index Terms: Milling, Residual stress, cutting conditions

I. INTRODUCTION

The machining of components is a persistent area of interest in the world of engineering design. Two of the most important parameters in component design are the life and performance of a component. As residual stresses are often undesirable, they can affect the performance if not suitably predicted and reduced. In orthogonal milling, many cutting factors are suspected to affect the residual stress- the feed rate, tool speed and depth of cut being some of them. The undesirable residual stresses caused by certain combinations of cutting conditions can be disastrous to the component, causing premature failure, deformation, and change in surface roughness and microstructure. This paper aims to establish the effect of tool speed and depth of cut on the nature and magnitude of residual stress. Seven rectangular specimens of AISI 1045 steel were subjected to a single pass of end milling. The residual stresses were measured by an X-ray diffractometer. These experimental values were confirmed by simulating the stresses and cutting conditions on an FEA software. The compressive residual stresses obtained were plotted against the speed and depth of cut. The relevance of residual stresses is always considered with the subject of optimal machining of components. The stresses developed in a component after the initial force is removed are known as residual stresses, and undesirable stresses can negatively impact the life and fatigue performance of a component (1). The effect of cutting parameters on the nature and values of residual stresses have been studied for different processes in the past (2). The effect of residual stresses on the surface integrity has also been an important field of interest, as neglected stresses can alter the desired properties of a component, thus posing a problem to industrial quality (3). Thus, predicting residual stresses becomes important. To do so, various measurement techniques have been reviewed, and are selected depending on the degree of accuracy necessary (4), (5). As experimental measurement of stresses can be expensive, many finite element models have been developed to corroborate experimental values (6). In these models, the process of material removal is modelled, a stress wave effect is observed (7) and a combination of the Lagrangian and Eulerian approach was developed (8), (9). The orthogonal milling process is often modelled (10), (11). Statistical models have also been developed to predict residual stresses within a certain error limit (12). Machining induced residual stresses are known to cause distortion, and it is observed to be different from the distortion caused by initial residual stresses present in a workpiece (13). This can be important when machining components for aircraft design. Metal cutting has been identified as a thermal process (14) and finite element models consider the thermo mechanical nature of milling. The effect of various cutting parameters and tool conditions on residual stresses have been found, such as the effect of tool edge radius (15) and feed rate (16).

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II. METHODOLOGY

A. Machining Conditions

Seven AISI 1045 steel specimens of 50*40*5mm dimensions were machined by a 4-flute end mill of 12mm diameter. The milling process was of a single pass on each of the workpieces. The speed was varied for the first three workpieces and the depth of cut was varied for the next four workpieces. Feed rate was kept constant at 160mm/min for all the specimens. The cutting conditions were as given in Table A.1.

Table A.1.Cutting condition

Sl.	Speed (RPM)	Depth of Cut (mm)
1	250	0.3
2	500	0.3
3	1000	0.3
4	1400	0.3
5	1000	0.4
6	1000	0.5
7	1000	0.6

B. Measuring Residual Stress

The residual stresses were measured using an X-ray diffractometer. Values were taken by considering the centre of each pass. The residual stress values obtained from the X-ray diffraction process are given in Table B.1.The negative sign indicates that the stress is compressive in nature. It is observed that the residual stresses become increasingly compressive as tool speed and depth of cut increase. Value 2 and value 4 differ from the expected trend and are assumed to do so due to initial tensile stresses present in those specimens.

Sl No.	Speed (RPM)	Depth of cut	Stress (MPa)
1	250	0.3	-170.9
2	500	0.3	-97.9
3	1000	0.3	-213.6
4	1400	0.3	-65.6
5	1000	0.4	-257.4
6	1000	0.5	-337.6
7	1000	0.6	-377.9

Table B.1 Experimental stress values

C. Finite Element Model of Residual Stresses

As a combined Lagrangian-Eulerian approach is best suited for models involving the analysis of both flow and structure, the Johnson-Cook models of material and damage have been employed in this paper. The workpiece is assigned properties of AISI 1045 steel and the tool is assumed to be able to absorb vibrations. Fig C.1 shows the visualization stage of experiment 2, revealing the assembly of the workpiece and tool.

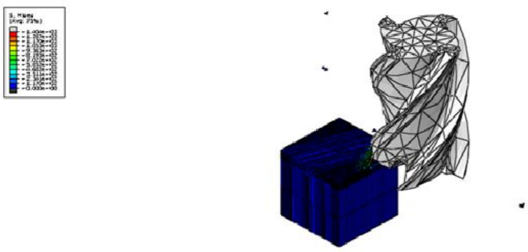

Fig C.1 Visualization stage

In the assembly stage, the tool was arranged with respect to the workpiece to get the desired depth of cut. In the load stage, speed and feed rate values were entered. The residual stress values from the FEM models are given in Table C.1, and were generated from the report files as well as nodal analysis of the model.

Table C.1 Residual stress values from Finite Element Analysis

Sl No.	Stress (MPa)
1	-171.4
2	-192.3
3	-240.2
4	-295.2
5	-257.4
6	-326.3
7	-352.8

III. RESULTS AND DISCUSSION

A thermo-mechanical FEA model was used to predict the residual stresses, and the experimental measurement of residual stresses were done by performing X-ray diffraction. The experimental and FEA values of residual stress are plotted against speed and depth of cut in Fig D.1 and D.2 respectively.

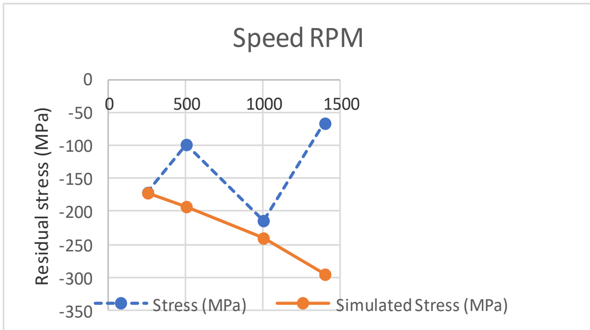

Fig D.1 Experimental and simulated values of residual stress vs tool speed

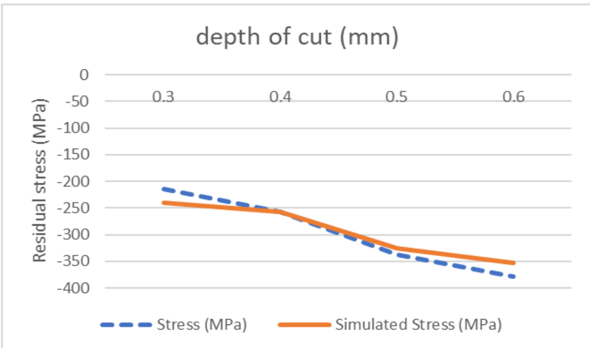

Fig D.2 Experimental and FEA values of residual stress vs depth of cut

The experimental and FEM model values of residual stresses were found to agree, with the exception of two experimental values, whose deviance can be explained by initial residual stresses present in experiment 2 and 4. Compressive residual stress was found to increase with the increase in speed, and with the increase in depth of cut. Further work could focus on optimizing cutting parameters and observing the effect of residual stress on functional properties of a component.

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