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Effects of Cutting Parameters on the Residual Stresses of SAE 1045 Steel after Turning

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Abstract. Surface residual stresses on machined parts may be undesirable in some parts, leading to problems over their lifetime. In order to study the effects of cutting parameters on the residual stresses of SAE 1045 steel after turning, tests were performed varying cutting depth, feed rate and cutting speed. For each of these parameters, four different conditions were tested, in order to understand their influence separately from the others. The tests were performed with tungsten carbide coated tool with 80° rhomboid tip morphology. Before being used in the tests, the samples were thermally treated through the normalization process, in order to obtain a regular grain size in each sample and reduction of the residual stresses present in the billet from the manufacturing process. The $\sin^2\Psi$ method, through the X-ray diffraction technique, was used to quantify the residual stresses. The samples were divided into 4 regions for the evaluation of the residual stresses, where the analyses were performed in the longitudinal and axis direction. The analysis of the residual stress presents greater variation for the depth of cut and feed rate. With the increase of the depth of cut, the tensile residual stresses reduce, presenting compressive values in the axial direction. With the increase of the feed rate, there is increment of the tensile residual stress.

Introduction

The study of residual stresses has been of great importance in the understanding of the contact mechanics, damage mechanics and fracture mechanics, with respect to the behavior of the materials. The residual stresses are an elastic response of the material to the spatial variations of a heterogeneous microstructure [1].

The manufacture industry has been demanding an increasing productivity. In machining processes, the tools are under constant evolution to attend this growing necessity of more severe cutting parameters. Some advances in cutting tools have been made such as the development of hard coatings [2].

In machining, in the processes of milling, turning, drilling and grinding, the final state of the residual stresses will depend on factors such as machined material, cutting tool, machining parameters and coolant. In these processes, the generation and modification of stresses are given by the localized heating and the contact pressure performed by the tool, which can generate tensile or compressive stresses [3, 4].

Residual stresses increase with most machining parameters increment, including cutting speed and tool corner radius [5]. Additionally, it is worth mentioning that compressive stresses are usually desired.

Some authors have investigated the influence of the cutting parameters in the residual stresses of the machined materials. Researchers found that the residual stresses tend to be more tensile for higher feed rates for a turned Iconel 718 [6, 7]. Some studies purpose a model to predict the residual stresses on a turned steel and show that the increase of cutting speed also increases the tensile residual stresses on the workpieces, according to the model [8]. Another analytical model analyzed the influence in residual stresses of machining parameters and tool parameters separately. According to this model, the depth of highest compressive residual stress increases with the increase of feed rate, and decreases with the increase of cutting speed [9].

This study aims to analyze the influence of the cutting parameters (cutting speed, feed rate and depth of cut) in the superficial residual stresses of turned pieces, in such a way that it can be used as reference when somehow it makes necessary to adjust the cutting parameters in manufacture industry in order to get higher productivity.

Experimental Procedure

Material and heat treating. The material used in the tests was the SAE 1045 steel with pearlitic/ferritic microstructure with chemical composition presented in Table 1.

Table 1 - Chemical composition of SAE 1045 steel tested

Fe [%]	C [%]	Mn [%]	Si [%]	Al [%]	S [%]
98,31	0,45	0,75	0,27	0,20	0,02

The specimens were heat treated through the normalizing process in order to standardize the grain sizes and the residual stresses.

For the normalizing heat treatment of the specimens' grain sizes, it was used as reference the ASM International Standard [10], which recommends the temperature of 880ºC. The furnace was kept at this temperature for 90 minutes to stabilize the temperature and standardize the specimens. After that, the specimens were withdrawn from the furnace and arranged for air cooling.

The specimens were produced to be tested with a minimum diameter of 29 mm. The Fig. 1 shows the specimen. The diameter of 15 mm was used to fix the specimen in the chuck, furthermore it is settled by the tailstock in the opposite face.

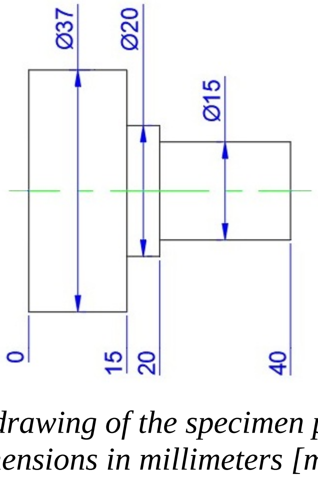

Fig. 1 - Schematic drawing of the specimen prepared for testing (dimensions in millimeters [mm])

Inserts. For each test specimen, a new insert was used, in order to reduce the influence of the tool wear mechanisms on the results of residual stresses.

The tool and tool holder geometry is described in Table 2.

A multilayer CVD coated tool (TiCN, Al_2O_3 and TiN) was used.

Table 2 – Tool and toolholder geometry used in the tests

Insert Shape	80º
Insert Clearence Angle	0º
Insert Corner Radius	0,8 mm
Approach Angle	93º
Axial Rake Angle	-6º
Radial Rake Angle	-6º

Tests. The tests were performed without cutting fluid. The parameters of Cutting Speed (Vc), Depth of Cut (ap) and Feed Rate (f) varied.

In order to quantify the influence of each variable on the residual stress, the following parameters were used: cutting speed (60/135/190/310 [m/min]), feed rate (0.06 / 0.18 / 0.30 [mm/rev]) and depth of cut (1.0 / 2.0 / 3.0 / 4.0 [mm]).

Residual stress measurements. After the tests, the specimens were analyzed in the XRD without the necessity of a previous handling of the pieces. For this analysis, a device was developed to fix and position the sample in the equipment, presented in Fig. 2. The measurements were carried out by X-ray diffraction using the iso-inclination method, the parallel-beam geometry and the anode (target) CrKα (2.289 Å). Residual stress was measured in the cutting direction and in the feed direction, considering the state of plane stress.

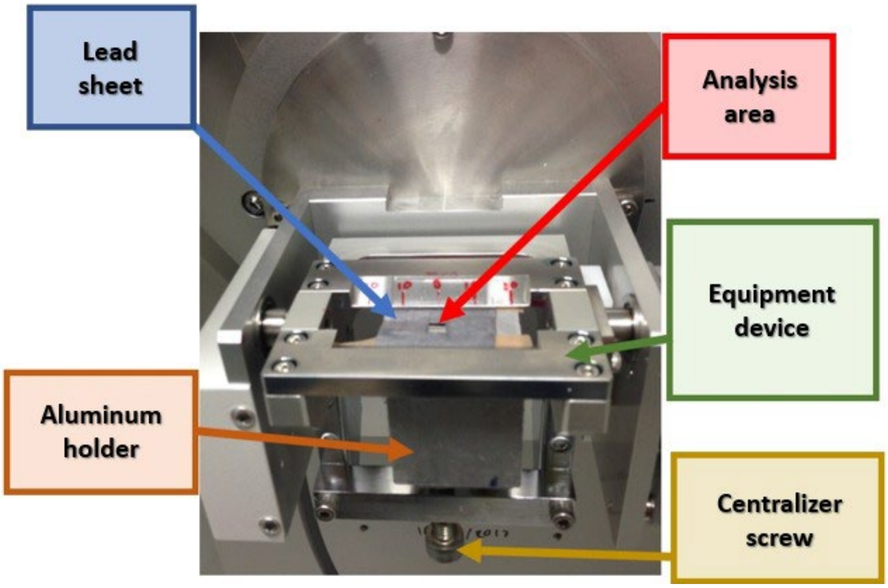

Fig. 2 – Positioning of the specimen for measurement in the XRD

Results and discussions

Results for variation of the cutting speed. The parameters of feed rate (0.18 mm/rev) and depth of cut (2.0 mm) were maintained. The results are shown in Table 3 and Fig. 3.

It is possible to observe an increase tendency of the tensile tensions with the increase of the cutting speed up to 190 m/min. For the cutting speed of 310 m/min, it was possible to observe a reduction in the tensile stress, which can be understood as a predominance of thermal loads up to the speed of 190 m/min and mechanical loads at higher speeds. An indicative that, for higher speeds, most of the thermal energy generated in the cut is coming out in the chip. Similar results were observed in the AISI 4340 steel study [11].

Table 3 – Surface residual stress results varying the cutting speed

V_c [m/min]	Residual Stress [MPa]	
	Cutting direction	Feed direction
60	260 ±15	-83 ±13
135	417 ±20	41 ±12
190	414 ±19	54 ±10
310	352 ±15	-24 ±07

[redacted]

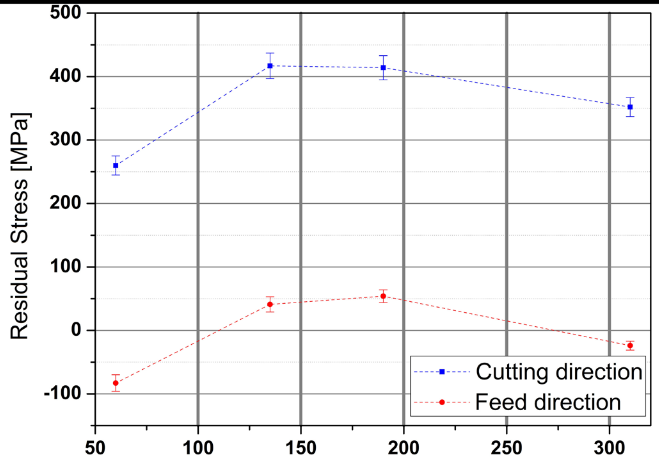

Fig.3 – Surface residual stress results, varying the cutting speed

Results for feed rate variation. The parameters of cutting speed (135 m/min) and depth of cut (2.0 mm) were maintained. The results are presented in Table 4 and Fig. 4.

The higher the feed rate, the greater the surface residual tensile stress. This gain is associated with the elevation of the cutting temperature, generated by the chip thickness increase, which boosts the heat generation related to the plastic deformations [11-13].

Results for variation of depth of cut. The parameters of cutting speed (135 m/min) and feed rate (0.18 mm/rev) were maintained. The results are shown in Table 5 and Fig. 5.

With the increase of the cutting depth, maintaining the parameters of cutting speed and feed rate, it was observed the reduction of the residual tensile surface stress (or elevation of the residual compressive surface tension), indicating elevation in the mechanical loading.

Table 4 – Surface residual stress results, varying the feed rate

f [mm/rev]	Residual Stress [MPa]	
	Cutting direction	Feed direction
0,06	286 ±13	-79 ±04
0,12	337 ±13	-83 ±09
0,18	417 ±20	41 ±12
0,30	469 ±20	182 ±10

[redacted]

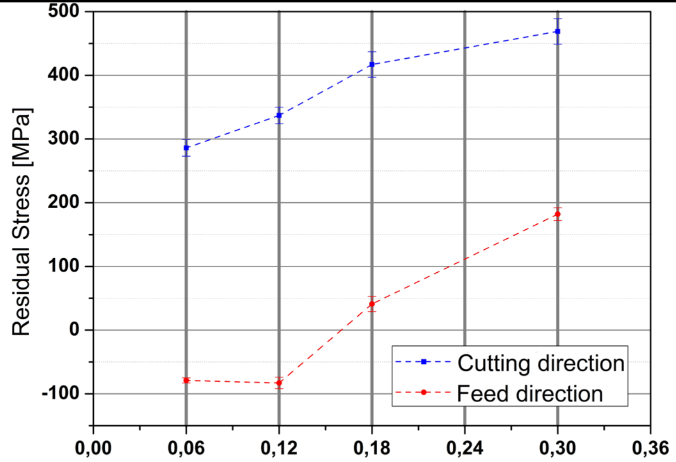

Fig. 4 – Surface residual stress results, varying the feed rate

Table 5 – Surface residual stress results, varying the depth of cut

a_p [mm]	Residual Stress [MPa]	
	Cutting direction	Feed direction
1,0	509 ±25	283 ±06
2,0	417 ±20	41 ±12
3,0	320 ±15	-164 ±12
4,0	285 ±11	-197 ±10

[redacted]

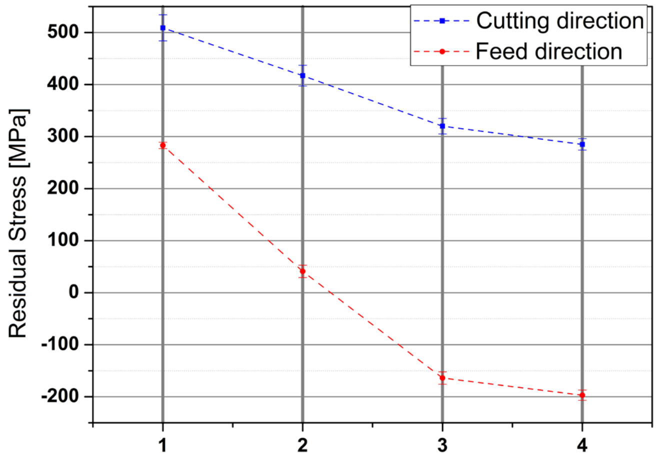

Fig. 5 – Surface residual stress results, varying the depth of cut

Summary

The parameter that influenced the variation of the residual stress the most, showing less tensile or more compressive values with its increase, was the depth of cut. The feed rate presented an inverse result, in which the increment of this parameter caused an increase in the residual tensile stress. The cutting speed was shown to be the parameter with less influence, showing an increase of the surface residual stress up to a speed of approximately 200 m/min. At higher velocities, there was a reduction of the residual tensile stress.

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