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Experimental and Numerical Investigation into Residual Stress During Turning Operation for Stainless Steel AISI 316

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K E Y W O R D S

Residual stresses, feed rate, cutting speed, X-ray diffraction, ABAQUS.

A B S T R A C T

RS (residual stresses) represent the main role in the performance of structures and machined parts. The main objective of this paper is to investigate the effect of feed rate with constant cutting speed and depth of cut on residual stresses in orthogonal cutting, using Tungsten carbide cutting tools when machining AISI 316 in turning operation. AISI 316 stainless steel was selected in experiments since it is used in many important industries such as chemical, petrochemical industries, power generation, electrical engineering, food and beverage industry. Four feed rates were selected (0.228, 0.16, 0.08 and 0.065) mm/rev when cutting speed is constant 71 mm/min and depth of cutting 2 mm. The experimental results of residual stresses were (-15.75, 12.84, 64.9, 37.74) MPa and the numerical results of residual stresses were (-15, 12, 59, and 37) MPa. The best value of residual stresses is (-15.75 and -15) MPa when it is in a compressive way. The results showed that the percentage error between numerical by using (ABAQUS/ CAE ver. 2017) and experimental work measured by X-ray diffraction is range (2-15) %.

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1. Introduction

Residual Stresses, or internal stresses, are the stresses which remain within an elastic part without having an exterior load applied to it. These stresses are important parameters that describe the surface and subsurface properties and subsequent performance of any mechanical component. They affect fatigue life, resistance to crack growth, static strength, corrosion resistance and magnetic properties, and depending on the particular stress distribution in any component, these properties can enhance or impair the part performance [1]. Residual stresses are tensile residual stresses or compressive residual stresses, compressive RS use to improve the performance of the component and life and prevent the cracks. Tensile residual stresses turn for increasing service stresses which lead to the failure of components [2], as shown in Figure 1. The benefits of residual stresses are represented by compressive residual stresses: [3] The compressive residual stresses are more important for product performance, more important for the life of the product which promoted service and excludes cracks. The limitations of RS represented by tensile residual stresses: Tensile residual stresses turn for increasing service stresses and lead to premature failure of a component and tensile RS leads to distortion, corrosion and cracking. To minimize the damage of residual stresses through: [4] From mechanical ways and heat treatment by reducing heat. The compressive residual stress is very important because it reduces fatigue life, corrosion and breakage of hydrogen compounds where it can be intentionally introduced by techniques such as shot peening and burnishing. ABAQUS is an effective engineering software that choose the finite element analysis to solve the problems of all stress analysis starts from simple linear analysis to the difficult non-linear simulations. [5] C.Y.Gao et al. [6] used to analyze high-speed metal cutting by FE software ABAQUS for showing the effect of Vc on workpiece made of stainless steel AISI 4142 on RS, the results showed that, as the Vc was increasing, RS show the decreased in tendency. E.Abboud et al. [7] used Titanium alloy Ti-6AL-4v for machining induced residual stresses, FE-based model of orthogonal cutting was developed, a full factorial orthogonal cutting experiments are conducted using the sharp tool it was uncoated carbide grade K68 to investigate the effect of both of feed rate and cutting speed on RS under finish-turning conditions. Surface residual stress was measured by XRD. The results were used to validate the FE model. The results showed that RSs were compressive in nature for the investigated finish turning. Naoufel B.M et al. [8] predicted the near layer of the surface Rs used orthogonal cutting in turning operation of aluminum alloy AA7075-T651, using an uncoated carbide tool. They calculated residual stresses by experimental measurements using the XRD method, the effect of the cutting speed and feed rate on machining residual stresses have been established and then correlated the results with FE. The results showed that the RSs are tensile.

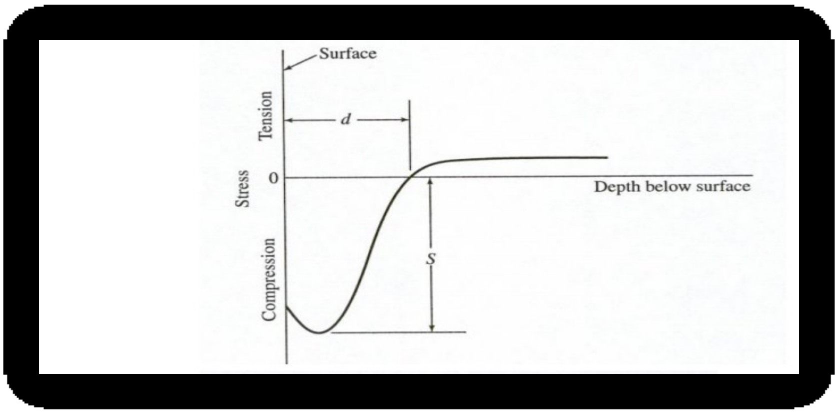

Figure 1: Example of residual stress. [2]

2. EXPERIMENTAL WORK:

A hollow shaft of stainless steel AISI 316 of 25 mm in diameter and 600 mm in length is selected, the analyzed and standard chemical compositions, mechanical, physical and thermal properties are listed in Tables I and II.

TABLE I: Analyzed the chemical composition of stainless steel 316

Element	C%	Si%	Mn	P%
Weight	0.004	0.432	1.74	0.027 1
Element	Ni%	Cu%	Cr%	Mo%

Weight	9.55	0.597	18.2	2.19
Element	S%	Fe%		
Weight	0.021 6	Balance		

TABLE II: Mechanical properties of stainless steel 316

Property	Valu	Units
Yield stress (off set 0.2%)	170	MPa
Tensile stress	485	MPa
Elongation	40%	(% in 50 mm)
Hardness Brinell (max).	217	HB
Hardness Rockwell (max).	95	B (HRB)

One type of cutting tool is used in this study. The insert used is coated carbide (PVD with TNMG) and it is selected as negative turning inserts according to specifications that are shown in Table III. Figure 2 shows the dimensions of the cutting insert tool in mm.

TABLE III: Tungsten carbide inserts TNMG.

Type	TNM
Material	100% raw new material of tungsten carbide
Chip breaker	DM- mainly recommended for semi finishing steel
ISO grade	P/M
Coating	CVD
Standard	ISO international standard

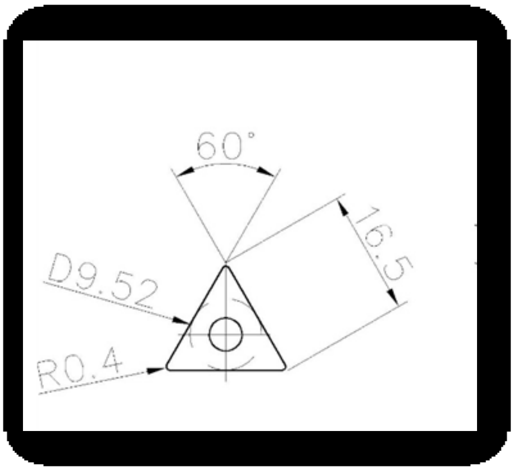

Figure 2: Dimensions of the cutting insert tool in (mm)

A tool holder type STACR\L 90 Deg. Screw clamp turning tool holder, Figure 3 shows the tool holder with his dimensions:

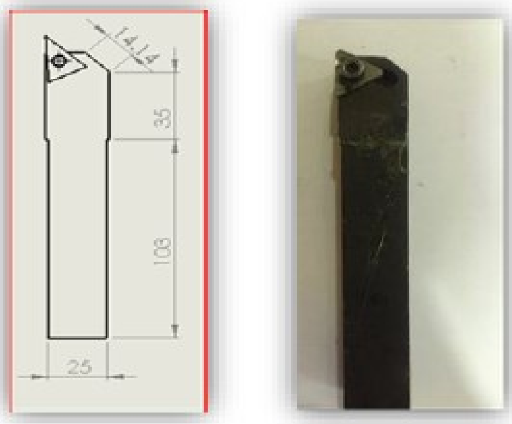

Figure 3: The tool holder and dimensions

The residual stresses were examined by x-ray device (XRD-6000), Table IV shows the technical specifications of the device.

TABLE IV:Technical specifications of the device

Name of the device	ORIONRKS 6000
Serial number of the device	1811020
Device manufacture	ORION
Model	RKS 1500 F-V-SP
Dimensions	W900 * D 700 * H 1600

The device is as shown in Figure 4.

Figure 4: X-ray diffraction device of residual stresses measuring

3. Finite Element simulations experiments:

FEM software ABAQUS/CAE (2017) is used to simulate the process of metal cutting. ABAQUS has the main units of a function called modules. It includes the indicators as shown in Figure 5 and is explained as follows:

Figure 5: Selecting a module.

Part

For the specimen: stainless steel 316 has been simulated using continuum element (8- C3D8R) 8 node linear brick, Figure 6 shows the shape of the workpiece. For the tool: tungsten carbide has been simulated using Hex-dominated use primarily hexahedral elements, Figure 7 shows the shape of the tool.

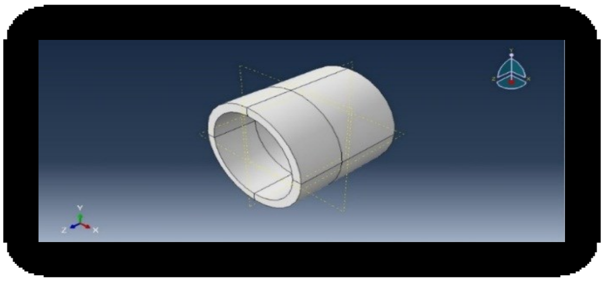

Figure 6: The workpiece

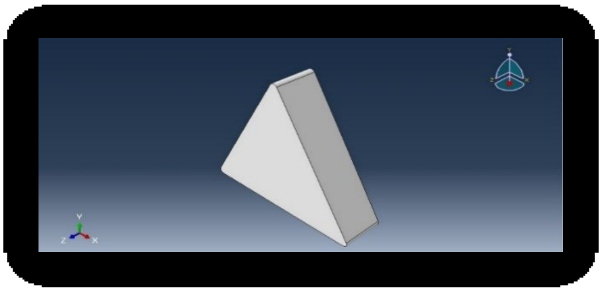

Figure 7: The tool

Property

In the workpiece of stainless steel 316 for elastic behavior knowing that the density= 7800 Kg\m^3, modulus of elasticity for the steel (E) = 200000 MPa and passion´s ratio (v) = 0.3, for plastic behavior knowing that the yield stress for steel= 170 MPa and use Johanson-cook.

Assembly

Use the Assembly module to create a form of parts and a form of other models and to a position. An Abaqus model has contained one assembly only, Figure 8 shows the assembly of two parts.

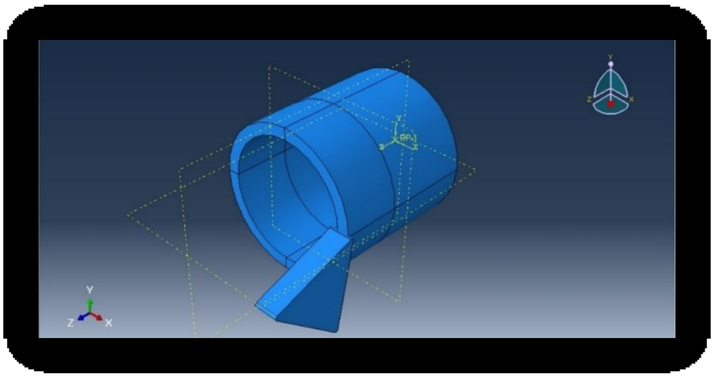

Figure 8: An assembly of the workpiece and the tool

Step

This section shows the use of time, the time-frequency used for 1120 r.p.m and 0.228 mm/rev = 1.175 for one cycle, and choose 1.275 to end one cycle with removal.

Interaction

There is an interaction between a region of a model and its surroundings. The contact generated friction and the coefficient of friction = 0.6

Load

The Load module allows determination, boundary conditions, loads, and predefined fields

Mesh

The Mesh module having tools that allow creating a (FE) mesh on an assembly created within Abaqus/CAE., Figure 9 shows the mesh generation.

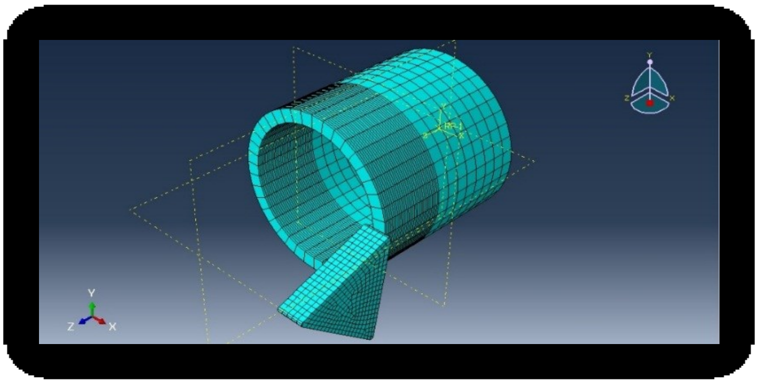

Figure 9: The mesh generation

Job

Used to finish all of the work involved in defining a model, use the Job module to make analyzing for the model.

Visualization

The Visualization module shows a graphic demonstration of FEM and results. It used to obtain models and result from the output database that used to control the input and used to show the output database.

4. RESULTS AND DISCUSSIONS

Figure10 shows clearly the effect on residual stress when feed rates are (0.228, 0.16, 0.08, and 0.065) (mm/rev) at cutting speed (71) m/min, and the values of residual stresses are (-15.75, 12.84, 64.9, and 37.74) (MPa) respectively.

The change in residual stress is characterized by two regions in this chart, in the first region, the residual stresses are increased by (15.9%) when the feed rate is increased from (0.065 to 0.08) mm/rev, while in the second region the residual stresses are decreased by (28.9%) when the feed rate is increased from (0.08 to 0.228) mm/rev.

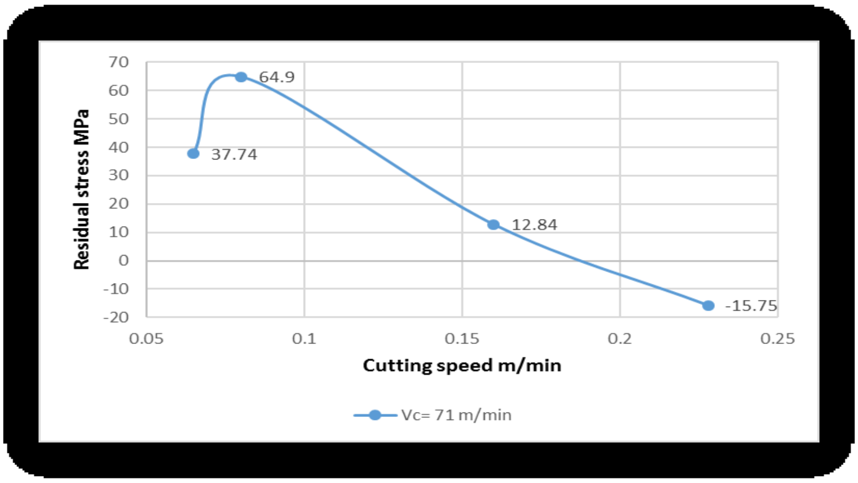

Figure 10: The effect of feed rates on residual stresses at cutting speed (Vc= 71 m/min)

Figure 11 shows clearly the simulated effect on residual stress when feed rates are (0.228, 0.16, 0.08, and 0.065) (mm/rev) at cutting speed (71) m/min, and the values of residual stresses are (-15, 12, 59, and 37) (MPa) respectively.

The change in residual stress is characterized by two regions in this chart, in the first region, the residual stresses are increased by (12.9%) when the feed rate is increased from (0.065 to 0.08) mm/rev, while in the second region the residual stresses are decreased by (25.8%) when the feed rate is increased from (0.08 to 0.228) mm/rev.

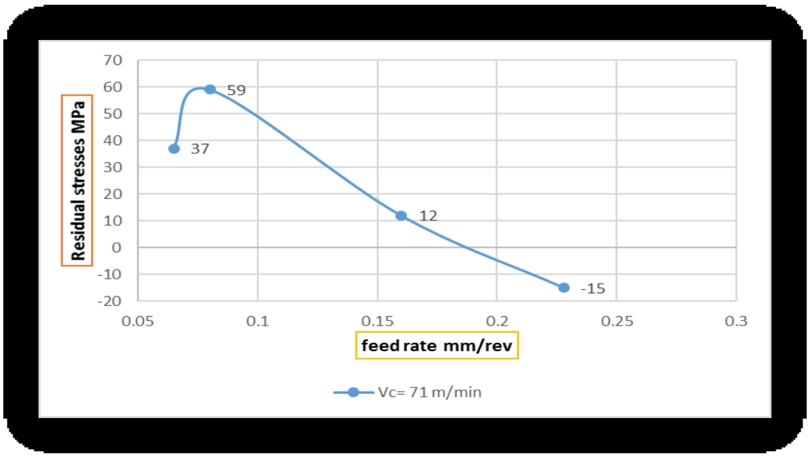

Figure 11: The simulated results of the effect of feed rates on residual stresses at cutting speed (Vc= 71 m/min)

It can be found that from the analysis of all testing cutting conditions, the predicted Rs shows the same results as the measured Rs, and it gives close results to the experimental data.

For explaining the compatibility of the measured and predicted values, the following figure shows the comparison between the experimental and numerical test for optimum cutting conditions, as shown in Figure 12.

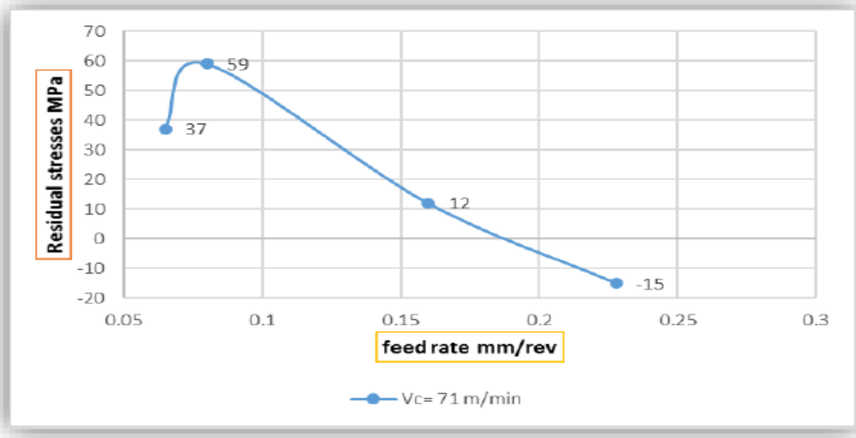

Figure 12: The comparison between the experimental and numerical

The simulation models with different cutting conditions are shown in Figures 13 and 14. For all figures shown previously according to [9] when the feed rate increases, strain in the axial direction decreases too leading to a decreased plastic deformation in the axial direction. Hence, the surface RS in the axial direction is slightly affected by the increase in the feed rate compared to residual stress.

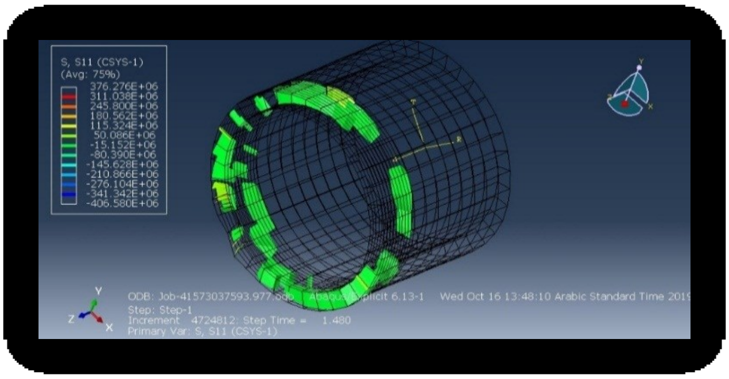

Figure 13: The simulated models with different cutting conditions. (Vc= 71 m/min, f= 0.228 mm/rev) RS= (-15) MPa

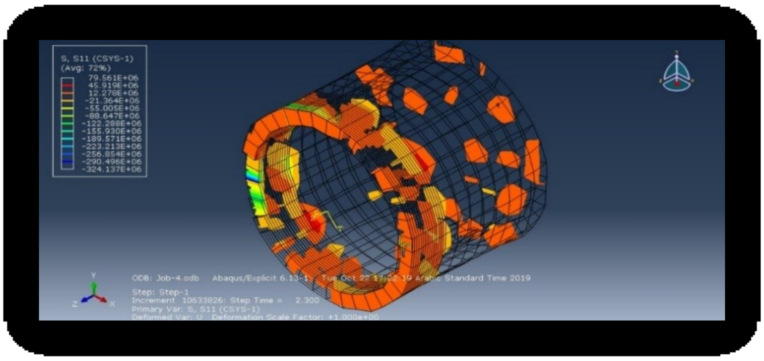

Figure 14: The simulated models with different cutting conditions. (Vc= 71 m/min, f= 0.16 mm/rev) RS= (12) MPa

5. CONCLUSIONS:

1) The FEM is used successfully to simulate the RS in orthogonal machining of AISI 316.
2) The feed rate affects the residual stresses and the results are (-15.75, 12.84, 64.9, 37.74) MPa
3) The simulated residual stresses using FEM in ABAQUS/CAE ver. 2017 showed a good agreement with experimental results with a range of (2-15) %.
4) FEM can be well used in simulation tests and compare with experimental work

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