The Effect of Machining on Surface Integrity of AISI 1018

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***Resumen*—El presente trabajo estudia los efectos de la velocidad de avance y profundidad de corte en la rugosidad superficial, microdureza, microestructura y propiedades mecánicas del acero AISI 1018. El método científico es aplicado a una metodología experimental que permite la cuantificación de resultados mediante pruebas de composición química, procesos CAD/CAE/CAM, análisis metalográfico y mediciones de dureza. Los resultados obtenidos contrastan la tendencia y la influencia de los parámetros de estudio, plantean causas y efectos favorables o desfavorables en la superficie del acero mecanizado dentro de un proceso de fabricación sostenible.**

***Palabras Claves*—AISI 1018, integridad superficial, rugosidad, microestructura, microdureza, manufactura sostenible.**

***Abstract*—The present work studies the effects of the feed rate and depth cut in the surface roughness, microhardness, microstructure and mechanical properties of AISI 1018 steel. The scientific method is applied to an experimental methodology that allows the quantification of results through chemical composition tests, CAD processes / CAE / CAM, metallographic analysis and hardness measurements. The results obtained contrast the trend and influence of the study parameters, raise causes and favorable or unfavorable effects on the surface of machined steel within a sustainable manufacturing process.**

***Keywords*—AISI 1018, surface Integrity, roughness, microstructure, microhardness, sustainable manufacturing.**

I. Introduction

The steel industry is a very active market worldwide, and it is planned that by 2018 there will be an expansion of 7.0%. In Latin America (LA) it is estimated that the production of this raw material will increase by 9.2%. The most important sectors related to steel are: construction, electrical equipment, metal products, mechanical and automotive machinery [1].

The importance of this study is based on the participation of AISI 1018 steel in the Latin America (LA) market due to its cost/benefit ratio, being also an easy welding and hardening material, suitable for parts that require cold forming, forging, bending or stamping [2].

The state of the art shows different experimental methods to evaluate the surface integrity depending on the mechanical properties. However, the analysis criteria of several authors such as: Leskovar [3], Lalwani [4] and Sasahara [5] maintain the same structure using variable machining parameters to study the metallographic changes. Therefore, the present work focuses on the influence that the feed rate and depth of cut at constant rotation speed exert on the surface integrity of AISI 1018 steel and how this affects microhardness and microstructure [6].

The revolution in the industry was an effect of the development of CNC machinery [7]. The combination of mechanical systems with electronic components has improved the industry in terms of time, cost and quality. CAX processes (Computed Help Processes), help minimize human errors in machining and optimize resources to introduce the concept of sustainable manufacturing. CAD programs allow the creation, analysis and modification of graphic representations of prototypes [8] and the CAE process supports the development of conceptual engineering with simulations of finite element methods to evaluate the design, durability and optimize the prototype. The CAM process, on the other hand, links the stage of engineering design with the manufacture of the final product.

The following sections describe the experimental methodology applied, the discussion of the results, the outstanding conclusions and the future work.

II. Methodology

This section describes the methodology used for assessing an AISI 1018 steel workpiece. The current methodology is based on experimental data obtained from a novel study case developed on a university research laboratory.

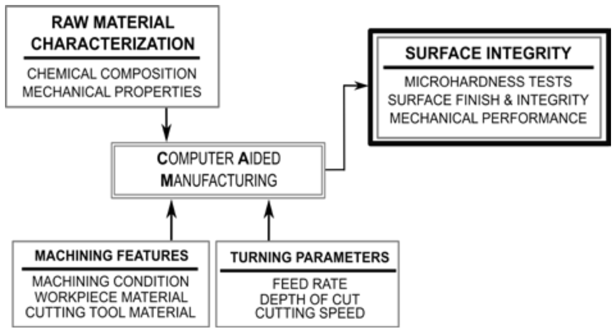

Fig. 1. Experimental Methodology.

Fig. 1 describes the pathway to study chemical and mechanical performance of machined workpiece. The raw material is the input, CAD processes support the experimental method, and the surface integrity analysis is the output. In the following paragraphs, each one of the mentioned aspects will be explained.

A. Raw Material Characterization

The steel selected for this study was the AISI 1018 since it has a wide range of industrial applications in the Ecuador, the test specimen has a diameter = 25.4 [mm] and a length = 70 [mm], the chemical composition and mechanical

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properties have been validated by experimental methods to ensure the methodology and results.

B. Computer Aided Manufacturing

The machining process was carried out on a CNC Lathe Romi C420. CAM was applied to control the machining characteristics and the turning parameters. The machining features to consider were machining condition, workpiece material, and cutting tool material.

The machining conditions of the specimens is a wet machining process, the lubricant used was Promax Taladrin (Valvoline), the cutting tool for machining was the insert DNMG 15 06 08-PM 4325 manufactured by Sandvik Coromant. The parameters of cut established in this study are: depth of cut, feed rate and rotation speed. The experimental method considers a constant rotation speed of 1200 [rpm] and is considered as variables to the depth of cut and the feed rate.

C. Surface Integrity

The integrity of the surface was evaluated by metallographic analysis and Vickers HV_{200gf} microhardness measurement applied to the load for 15s, following the ASTM E407-99 and ASTM E384 standards.

The last stage proposed by the methodology establishes the link between the manufacturing process, the deformation of the material and the variation of the mechanical properties [9], [10].

D. Mechanical Performance

According to Cahoon, microhardness is an adequate parameter to calculate the yield strength (σ_y) in a material. The relationship between these parameters is shown in the following equation [11].

$$\sigma_y = \left(\frac{H}{3}\right) \cdot (0.1)^{m-2} \tag{1}$$

Equation (1) represents the relation of mechanical characteristic, where H is the hardness obtained from the test in Vickers scale, and m is the coefficient of hardening by deformation established by Meyer is equal to 0.26 for low carbon steels [12].

Furthermore, strains (ε) involved in plastic deformation due to machining operations can be related with yield strength, C is a constant of 0.801 [9].

$$ln(\sigma_y) = ln(C) + (m-2) \cdot ln(\varepsilon) \tag{2}$$

$$\varepsilon = e^{\frac{ln(\sigma_y) - ln(C)}{m-2}} \tag{3}$$

Equation (2) represents the mathematical model that helps to relate the mechanical properties such as yield strength with deformation and mechanical characteristics such as the strain hardening coefficient and the deformations produced in the region affected by machining.

Table I shows the two case studies proposed in this paper, for case A it was established as a variable at the depth cut (a_p) and as constants to the parameters feed rate (f_n) and rotation speed (ω). Case B considers the feed rate (f_n) as a variable and as constant to the parameters depth cut (a_p) and rotation speed (ω).

TABLE I
STUDY CASES CRITERIA

	Case A	Case B
Feed rate [mm/rev]	0.2	0.3 / 0.4 / 0.5
Depth of cut [mm]	0.5 / 1 / 1.5	1
Rotation speed [rpm]	1200	1200

III. RESULTS AND DISCUSSION

The following paragraphs show the results obtained from the application of the experimental methodology in the study of surface integrity changes due to machining.

A. Raw Material Characterization

Due to chemical composition tests, the raw material was ratified as heat-treated steel. Based on chemical parameters, the results demonstrate the belonging of this steel to AISI 1018 type.

TABLE II
RAW MATERIAL CHEMICAL COMPOSITION

Results	% C	% Mn	% P	% S
Experimental	0.15	0.572	0.031	0.017
ASTM A108	0.15 < C < 0.20	0.6 < Mn <0.9	≤0.04	≤0.05

Table II shows the results obtained from the chemical composition study. Although, manganese is not within the established, the variation is very small, this variation may be due to the fact that the raw material is coming from scrap and can influence the results.

B. Surface Integrity

Roughness. The following results show the influence of the machining parameters on the roughness. Fig. 2(a) shows that, when increasing the feed rate during the cutting operation, the surface roughness is affected in a negative way (case A).

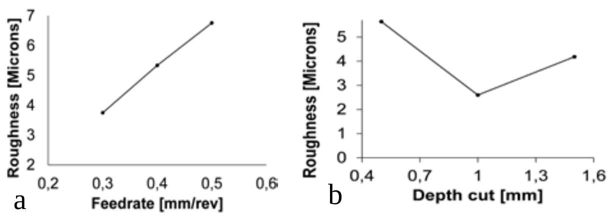

Fig. 2. Effects of feed rate and depth cut on roughness case A and B.

For the case of the study B, when the depth cut is less than 1mm (see Fig. 2b), the surface roughness of the work piece tends to decrease, showing a better surface quality. On the contrary, at depths cut greater than 1mm, the roughness is increased negatively affecting the surface of the element.

Microhardness. The hardness of the base material was evaluated from the surface towards the center of the steel shaft, obtaining an average value of 206 HV_{200gf} ±10.

Fig. 3 represents the effect of the depth of cut and the feed rate on the microhardness. The highest values were obtained with indentations made at depths less than 100 microns with an average value of 236 HV_{200g}, corresponding to the area of greatest plastic deformation, henceforth the hardness decreased until obtaining a constant trend.

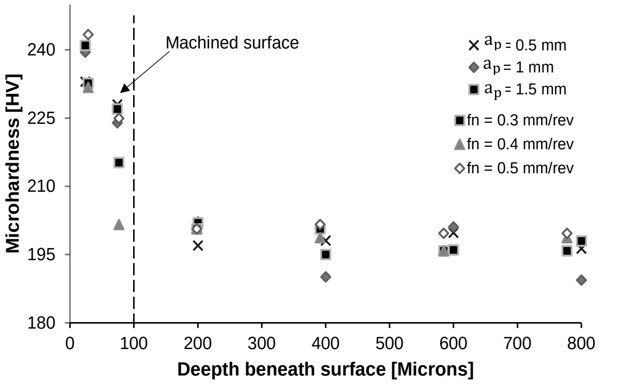

Fig. 3. Microhardness on AISI 1018 machined surface.

Surface metallographic analysis. The grain size of the base material was measured before machining in order to determinate the influence of machining on microstructure variations. The grain size in the machined area, and in the center of the shaft was ASTM No 8.

Fig. 4 shows the microstructures when the parameters of Case A were applied. There is a great deformation caused by the contact between the cutting tool and the surface of the work piece. The ferrite grains (light color) and pearlite (dark color) elongate in the cutting direction and the plastic deformation produces an induced hardening, which increases the microhardness in the machined surface by increasing the depth of cut.

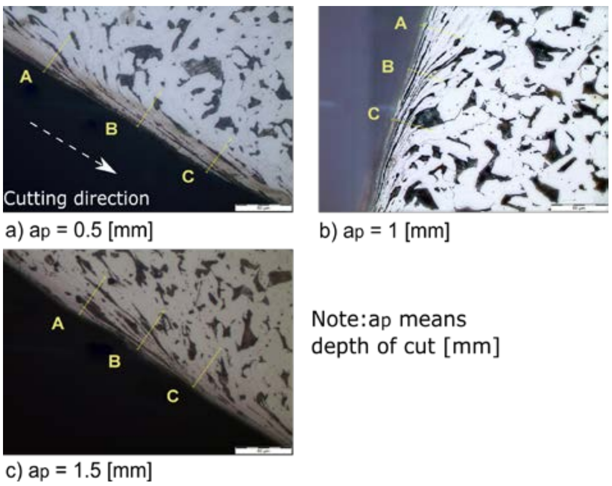

Fig. 4. Surface hardening, Case A, 500X.

Table III shows the plastic deformation induced in the material due to the contact of the cutting tool with the work piece during the machining of the surface. It is possible to identify an increase in plastic deformation as the depth of cut increases.

TABLE III
DEPTH CUT EFFECT ON PLASTIC DEFORMATION

a_o [mm]	A / 1 [μm]	B / 2 [μm]	C / 3 [μm]
0.5	28.37	27.73	28.08
1.0	38.75	34.20	37.33
1.5	42.6	42.71	43.99

For case B, the microstructure and plastic deformation obtained by varying the feed rate is very similar case A.

Table IV shows the plastic deformation induced in the material because of the variation in feed rate. Furthermore, higher levels of plastic deformation are an effect of high feed rate values.

TABLE IV
FEED RATE EFFECT ON PLASTIC DEFORMATION

f [mm/rev]	A / 1 [μm]	B / 2 [μm]	C / 3 [μm]
0.3	19.0	18.11	19.30
0.4	38.75	34.20	37.33
0.5	42.60	42.71	43.99

Mechanical Performance. Yield strength, and deformation are the mechanical features carried out from the application of Equation 2, and experimental data obtained from microhardness tests.

Fig. 5 relates the yield strength with material's hardness. Demonstrating that changes in feed rate or depth of cut produces a positive slope variation in material's yield strength.

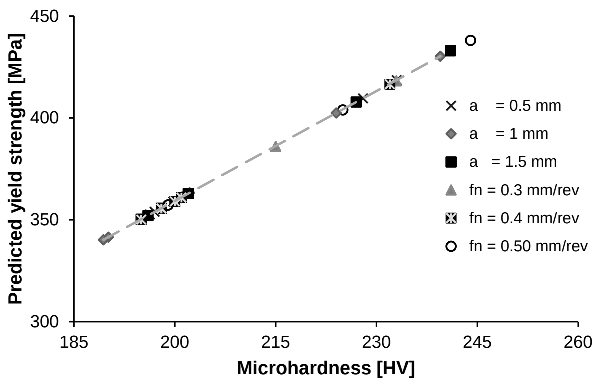

Fig. 5. Yield strength due to microhardness.

Fig. 6 shows that the highest deformation generated by strain is in the machined area. The latter results are not affected by machining parameters.

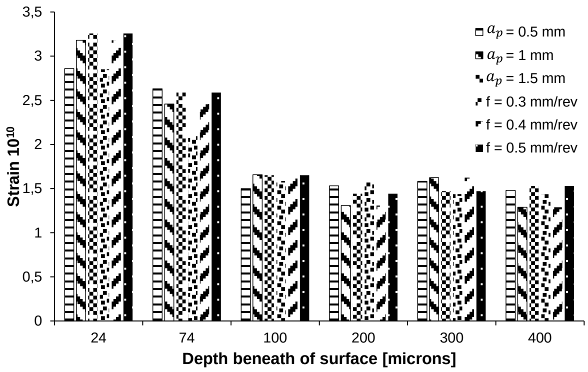

Fig. 6. Behavior of Strain versus depth beneath of surface.

Electron Microscopy. The quality and surface texture were performed by SEM analysis. Fig. 7 shows the generation of marks and microcracks on the machined surface, generated by the displacement of the cutting tool when separating the chip.

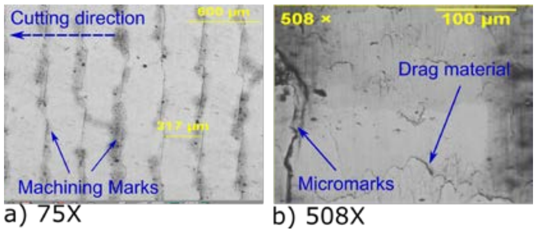

Fig. 7. SEM of the longitudinal advance of the cutting tool.

IV. Conclusions

The feed rate exerts a greater influence on the surface roughness in the machined sample, since by increasing this parameter the slope remains positive and growing in the range of 0.3 – 0.5 mm/rev. The depth cut in the range of 0.5 – 1 mm induces a favorable behavior when reducing the roughness by 53%, however, when increasing the penetration of the cut greater than 1 mm the slope again takes a positive value. The increase of 14.5% (206 – 236 HV_{200gf}) in the surface hardness of the two samples, is due to the superficial plastic deformation caused by the machining and to the direct affectation of the ferrite and perlite phases that are also deformed causing in this region a displacement and accumulation of dislocations, that increase the yield strength, mechanical resistance and hardness. Plastic deformation in the workpiece surface is highly influenced by depth of cut. The study showed a deformation from 28 to 44 [microns] and a deformation of 29.4% lower when feed rate was established as variable in the experimental method.

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