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Influence of part's stiffness on surface integrity induced by a finish turning operation of a 15-5PH stainless steel.

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Abstract

The turning process is well known to modify the surface integrity, and especially the residual stress profile as well as the surface roughness. Most of the past investigations have been conducted with large and stiff samples, whereas many small parts are machined in industry. So this paper aims at characterizing the influence of part's stiffness on residual stresses and on surface roughness when machining a 15-5PH steel. It is highlighted that a lack of stiffness can dramatically modify the residual stress state in the surface due to radial vibrations and can lead to large deviations of the surface integrity state.

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Keywords: Residual stresses ; surface roughness ; surface integrity ; vibration ; stiffness

1. Introduction

Precipitated hardening (PH) stainless steels, like 15-5PH, show excellent mechanical properties, low distortion, excellent weldability and good corrosion resistance which make them excellent candidates for aeronautical and nuclear industries. Predicting the fatigue resistance of mechanical parts is crucial for these industries. Several studies [1] have shown that fatigue resistance is directly and significantly influenced by several parameters such as surface roughness, residual stress and microstructure, which are commonly summarized by the designation "surface integrity". Residual stresses are induced by a complex combination of thermal and mechanical loadings. Mechanical loadings (pressure and shear stresses) generally induce compressive residual stresses through a plastic deformation on the surface of the material. On the contrary, thermal loadings lead to tensile residual stresses due to important thermal gradients. When mechanical and thermal loadings are strongly combined in a process, as they are in machining, it is very difficult to predict if compressive or tensile residual stresses will be prevailing. The final surface integrity strongly depends on the last operation which has a major responsibility [1-2]. Among the finishing operations applied to critical parts, longitudinal finish turning is widely used. Different 2D and 3D numerical models have been developed during the last decades to predict residual stresses state after turning of various workmaterial [3-9]. Regarding the 15-5PH stainless steel, Mondelin et al. [10] developed a 3D numerical model to predict the residual stress state after turning of this material. Otherwise this model is now available in industry as a package in the SYSWELD® software.

All these models have a weak point: They have assumed that the workpiece as well as the cutting tool have an infinite stiffness. So, they concentrate their development on the improvement of the thermomechanical loadings characterization or of the numerical formulation. Unfortunately, a large number of parts are not that stiff and a perfectly stiff machining system does not exists. There is always an elastic deformation (even small) of the workpiece and of the cutting tool. As a consequence, very small vibrations may occur in finish turning, even when nothing can be observed by human eyes on the surface roughness or by earing. Outeiro & al. [11] have shown that vibrations can influence the residual stress state. The present work does not focuses on the

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residual stress state when evidences of vibrations are found on the surface after machining, because, in this situation, parts are not allowed to be used in mechanical system, especially for safety and critical components. Such parts are either improved by a superfinishing process (mass finishing, belt finishing, ball burnishing, etc…) or scrapped.

The objective of this work is to investigate the influence of a small lack of stiffness, without any evidence of vibrations, on the residual stress state in turning of a 15-5PH stainless steel.

2. Surface integrity in stiff turning

The workmaterial used is a 15-5PH martensitic stainless steel. Bars have been heat treated in the H1025 state (quenched from 1020-1050 °C followed by annealing for 4 hours at 550 °C and air cooling). Its Brinell hardness and average grains size are around HB350 and 30 to 40 µm, respectively. This grade is commonly used for power transmission in aeronautical applications.

The samples were prepared by turning of a cylinder having a diameter of 150 mm, clamped thanks to 3 adjusted jaws on one side and a running tailstock centered on the other side as shown in Fig. 1. The cutting conditions were selected based on the recommendations of our industrial partner in accordance with its current practices.

Surface integrities of five samples thus obtained was characterized: surface roughness, residual stress, and microstructure were analyzed.

Regarding surface roughness, a typical profile with circular grooves has been obtained. The average surface roughness parameter "Ra" was around 1 µm whereas the theoretical values was calculated around 0.86 µm (perfect cut surface with a perfect circular groove having a radius equal to the edge radius of the cutting insert 1.2 mm).

Regarding microstructure, Fig. 2a presents an example of SEM and EBSD cross section perpendicular to the cylinder axis. An affected layer is clearly visible on the surface. The thickness of the altered microstructure is limited (10 to 15 µm). Two zones can be clearly distinguished. In the first external layer, the EBSD analyses reveal a finely recrystallized layer on the surface with a thickness around 2 µm. Then, a deformed layer is present with a thickness between 7 and 10 µm. Finally, the bulk material is observable with the original grain shape. Mondelin & al. [12] have made similar observations for the same 15-5PH alloy after turning. They report that this grain refinement corresponds to a dynamic recrystallization phenomenon, which is induced by the severe thermomechanical load generated by the turning operation, and not by a transformation of martensite into austenite. Indeed, Mondelin & al. [13] have shown that, during a turning operation, the very high heating and cooling rates in the cutting zone do not allow this transformation.

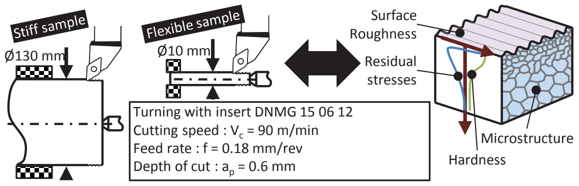

Fig. 1. Presentation of experimental cutting parameters and of the surface integrity parameters.

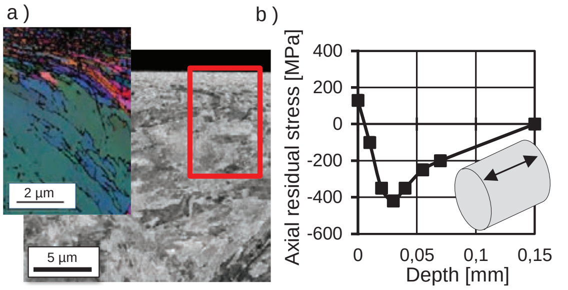

Fig. 2. (a) SEM and EBSD observations of microstructure after turning a stiff sample; (b) resulting residual stress profile in axial direction.

Fig. 2b presents the residual stress profiles in axial direction according to the sin2Ψ method. The residual stress profile after "stiff" turning shows tensile stresses on the surface, followed by a peak of compression. The thickness of the affected layer is around 0.15 mm. This hooked shaped profile is in agreement with the residual stress profiles obtained by Mondelin et al. [10] after turning of a 15-5PH.

3. Residual stress after flexible turning

For this experimental campaign, 7 cylinders having a diameter of 10 mm and a length of 110 mm have been finish turned as described in Fig. 1. Samples have been clamped with 3 adjusted jaws on one side and a running tailstock centered on the other side. Two cuts were performed in order to ensure that the last one has the desired depth of cut.

The surface roughness, as well as the surface axial residual stress, have been characterized in four angular positions around the center of the sample, where the flexibility effect is at its maximum. The surface roughness measurements are plotted in Fig. 3a and the residual stress values are plotted in Fig. 3b. Fig. 3a shows a small dispersion of surface roughness, which is not that important compared to the theoretical value. Additionally, it should be explained that no vibration was observable on the machined surface and that no particular noise was detected during cutting operations. On the contrary, Fig. 3b exhibits very large scatter for the surface axial residual stress level between two samples (Δ280 MPa), but also all around a sample. Most of the samples shows surface tensile residual stress, but one has compressive residual stress on its surface whereas its surface roughness is in accordance with others. This reveals that the thermomechanical loadings supported can vary during cutting and between the samples. Fig. 3c plots the average surface roughness Ra against the mean axial residual stress around each sample for flexible and stiff samples. The large deviation appears also clearly for flexible samples, whereas stiff samples exhibit more stable surface integrity. Thus, this deviation is attributed to the flexibility of the samples.

In order to point out the influence of the stiffness, cutting forces were recorded during the machining of the 7 samples.