Effect of Residual Stresses on the Distortion of Components after Machining

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The distribution of residual stresses induced by machining can affect the ability of a component to withstand severe loading conditions in service and may cause dimensional instability (distortion) during machining [1-4]. It is critical to be able to predict and thus control the residual stresses due to machining in order to enhance component performance. This is particularly important when critical structural components are machined, especially those used in the aerospace sector where productivity improvement and consistent part dimensionality are important [1].

Several groups have attempted to develop finite element approaches to predict residual stresses due to machining. The problem with the current models is that they do not take into account the initial residual stresses present in the raw material due to prior thermo-mechanical processing. To evaluate the initial stresses created by manufacturing and thermal processes, a non-destructive method is preferred, such that the parts can subsequently be used in machining tests [5]. Neutron diffraction is the best non-destructive method in this case because of the high penetration depth of neutrons, which allows data to be collected from all regions of a bulk specimen.

The objective of this research was to evaluate the impact of the initial residual stresses and machining stresses on the distortion of machined parts. Processes that minimize the residual stresses are now available on the market thus making it possible to carry out a comparative study on the influence of the constraints present before and after machining for different residual stress distributions. Therefore, we evaluate the residual stresses before and after the machining of a component for standard and for controlled process aluminums (see Figure 1).

Measurements were taken on six components before machining: three on the standard material and three on the controlled process material with low residual stresses. Because of the measurement time and the number of components to be measured, it was not possible to make a complete billet mapping. For each part, measurements were taken at 190 points corresponding to critical places where the component will be machined. Thus it was possible to compare the constraints before and after machining. Measurements were made using the {311} plane.

The results obtained lead to several observations. Initial measurements showed that there was symmetry in the residual stress distribution for standard material in the longitudinal direction only. For material with controlled process, there was symmetry in three directions: longitudinal, transverse and normal. Secondly, a high level of consistency was observed between specimens of the same material. However, the two types of material had different stresses distributions. The stresses obtained for aluminum with the controlled process showed weak variations and were always very close to the zero, but the curves obtained for standard aluminum showed more significant variations (Figure 2). The directions of the constraints, tension or compression, are not the same for the corresponding positions of measurements on the two materials. These variations could be at the origin of the deformations generated following the addition of the residual stresses induced by machining. Some researchers claim indeed that distortion can be generated when the stresses added by machining exceed the yield point of the material [6].

The neutron diffraction measurement method does not make it possible to measure the distribution of machining residual stresses through an entire thin wall of 0.080” [2 mm]. But it was possible to obtain the average stress in a point located at the center of the wall. The positioning of the points was critical because of the 2 mm measurement volume. Since the machined components were not straight, several wall scans were carried out in order to compensate for part distortion. We found that the distribution of stress for the machined part with standard material and with controlled process material correlates well with the geometrical deformations.

Thus, use of material whose process is controlled to minimize initial constraints solves the problem of the distortion because the residual stresses present in rough material are partly responsible for the distortion. All the parts machined in standard material underwent deformations while the parts machined in material with controlled process underwent very few deformations (see Figure 3). The neutron diffraction method shows that the distribution of the constraints, their signs, and their intensities can be at the origin of the deformations.

In the future, it will be interesting to repeat measurements on a standard billet and a controlled process billet by carrying out a complete mapping of the component. The results obtained would then be easier to analyze and they could possibly be used to solve the problem with the finite elements method. Also, a difference in the intensity of the neutrons beam was observed for the two types of aluminums during measurements. This observation suggests a difference in the granular structure coming from the forming processes. According to the theory, the grains of standard aluminum have a lengthened form in the rolling direction while those of controlled process aluminum are smaller and more uniform [7]. The size and the orientation of the grains could possibly have an influence on the distribution and the amplitude of the residual stresses.

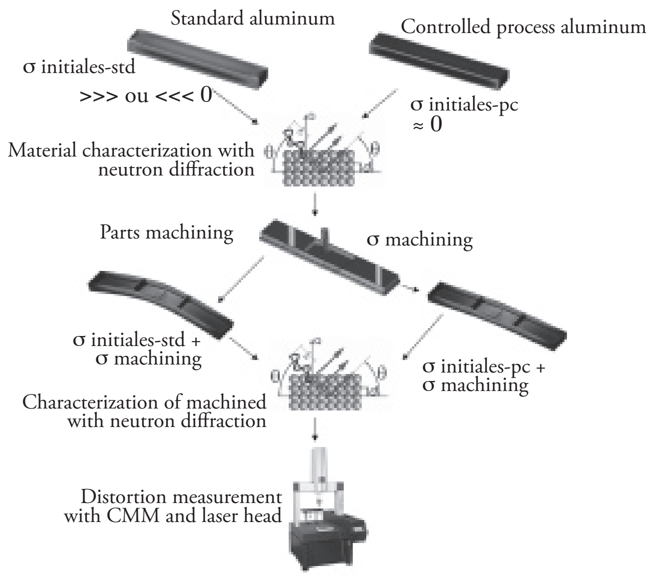

Fig. 1 *Methodology used to compare the distortion of parts for both types of aluminum.*

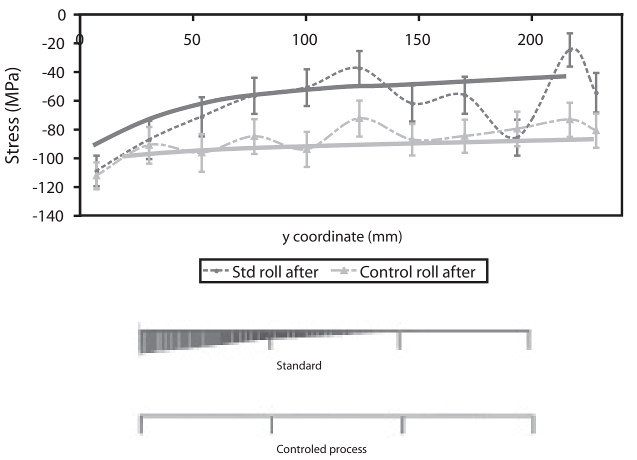

Fig. 2 *Residual stresses after machining in the rolling direction for the standard and the controlled process materials. The lower panel shows a 2D representation of the parts deformation measured with a 3D laser scanning technique.*

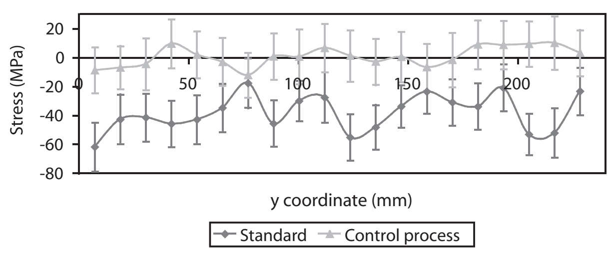

Fig. 3 *Raw material normal residual stresses in the Y direction for the standard and the controlled process aluminum.*

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