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A new approach in residual stresses analysis by Speckle Interferometry

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Abstract

The knowledge of residual stresses allows a reliable prediction of structure performances evolution, such as service life [1-3]. In this paper, we develop a new method for residual stresses determination combining Electronic Speckle Pattern Interferometry (ESPI) with the machining of a groove. The internal stress field is perturbed as the depth of the groove is increased incrementally. The structure finds a new equilibrium state generating displacements which are measured using ESPI. This method was tested on an aluminium alloy AU4G plate treated locally by an ultrasonic shot-peening. The investigation of the images obtained with the phase shifting technique and fringe patterns, makes it possible to analyze, simultaneously, the stress profile along two directions: along the depth of the structure, and along the groove direction.

Introduction

Several methods are available for measuring residual stresses, the diffraction methods (X-rays, neutrons), the ultrasonic methods, the incremental hole-drilling method, etc [4-5]. With these methods we obtain the stress field in one direction. The method that we propose allows analyzing the stress profile, in 2D, along two directions. It is based on the principle of stress relaxation during a machining operation. The structure is mechanically disturbed by machining an incremental groove of 2 mm width. The structure finds a new equilibrium creating, on the surface, displacements or deformations. The displacement field is measured using Speckle interferometry.

Experimental procedure

The ESPI technique

Illuminating an optically rough surface with coherent laser light generates a grainy interference pattern. The distribution of these speckles is characteristic of the surface being illuminated.

In the case of the ESPI technique, these speckle patterns are captured with a CCD camera, before and after mechanical perturbation of the component. Correlation fringes will be obtained, when two images of speckle patterns are subtracted.

The ESPI offers many advantages; it is a full-field measuring technique, without contact and does not require any particular preparation of the structure [6-7].

Experimental set up

A system combining an optical and mechanical setup was designed, as shown in Fig.1. The output of a continuous He-Ne Laser, with a wavelength $\lambda = 632.8$ nm and a power of 75 mW, was divided into two symmetric beams by a beam splitter. Each beam was reflected by two mirrors and expanded using microscope lenses and pin holes for spatial filtering. Such an interferometer is sensitive to in-plane displacements and the sensitivity vector is perpendicular to the groove ($S = 0.447 \mu\text{m}/\text{fringe}$).

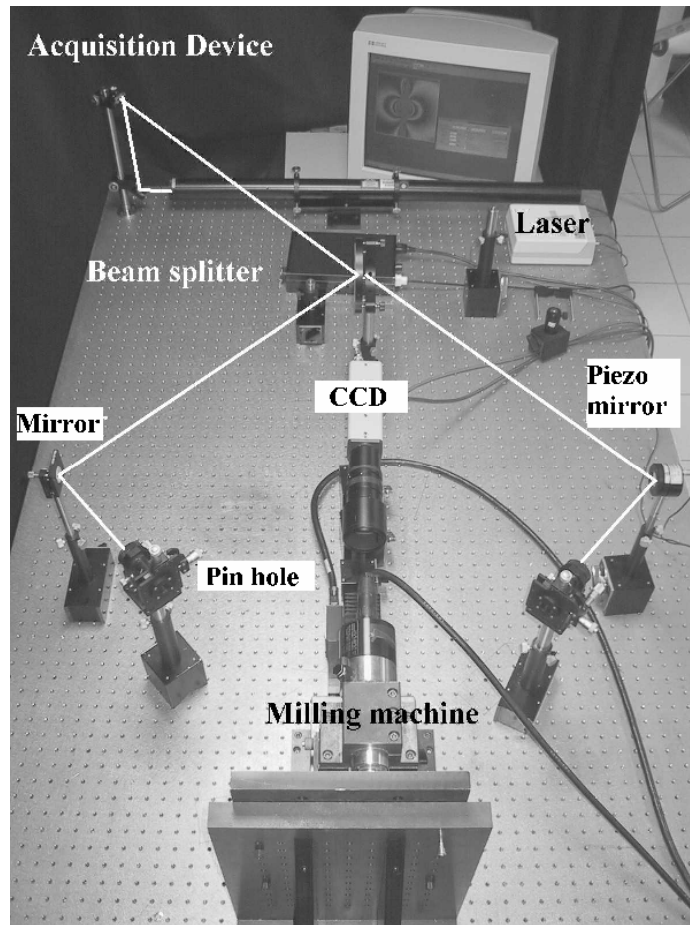


Fig [1] Experimental device

Phase shifting was produced with one of the mirror, which was mounted on a piezoelectric transducer. The images were captured by a CCD camera connected to a computer. The test specimen was a rectangular plate made of aluminium alloy AlCu4Mg (AU4G) which was treated by ultrasonic shot-peening to produce a band with compressive residual stresses like shown in Fig.2.

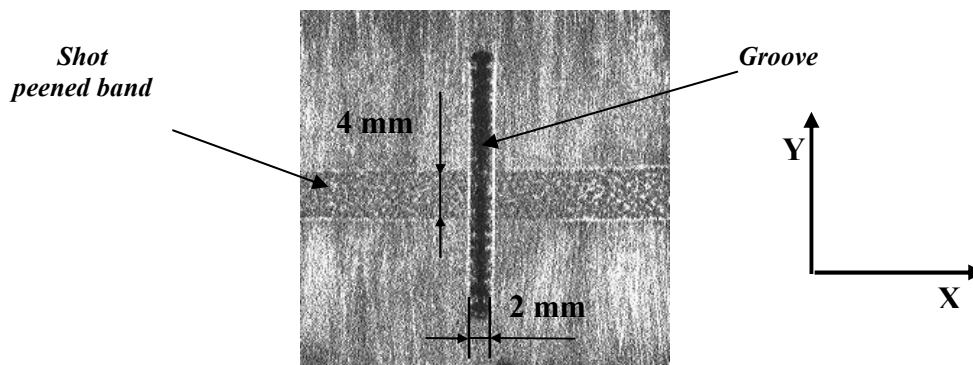


Fig [2] Photograph of the groove and of the shot peened band. The sensitivity vector of the interferometer is in x direction

The machining of the groove [Fig.1] is performed by a small milling machine. The penetration depth of the milling tool was controlled automatically with a precision of $0.2 \mu\text{m}$. we chose a rotation speed of 5000 rpm and a feed rate of $1 \mu\text{m/s}$.

The groove was machined incrementally, like in the incremental hole-drilling method, to determine the profile of residual stress along the depth and along the groove. The displacement generated by the stress relaxation is measured by Speckle interferometry [8-9].

Results and discussion

The exploitation of the images obtained by phase shifting [Fig 3] and with correlation fringe patterns [Fig 5] allows to determine, for each increment, the displacement field on the surface of the tested specimen.

Phase shifting results

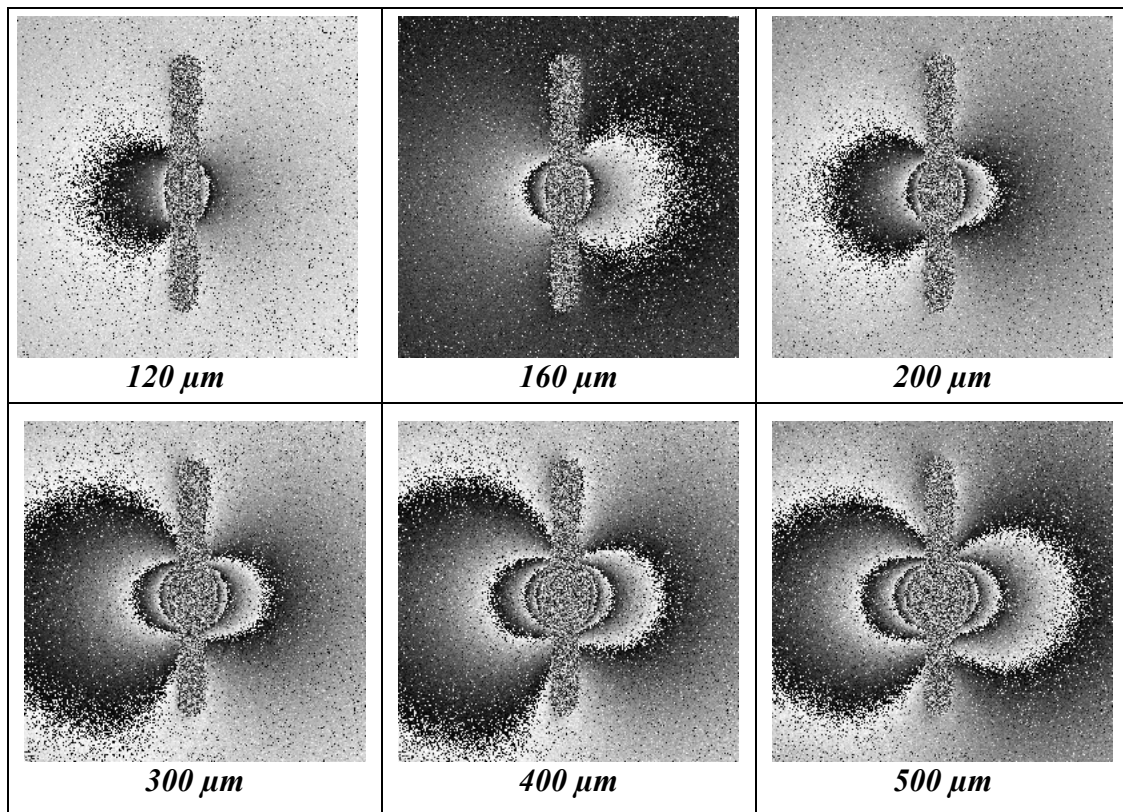


Fig [3] Phase distribution obtained for each increment

Fig.3 shows the wrapped phase distribution that was obtained for the six depths drilled. These phase maps were obtained by subtracting two images of phase. The first one is the reference image, in the undeformed state, and the second image is the image obtained after each machined increment, in the deformed state. Images are captured for each increment after each depth drilled. We can observe that the number of fringes increases. This is due to the increase in stress relaxation as the machining gets deeper. It can be seen that the form of the fringes is different than fringes obtained with the incremental hole-drilling method [10-11].

For each increment displacement data along several lines are extracted. Image processing was performed on a PC platform, using commercial software.

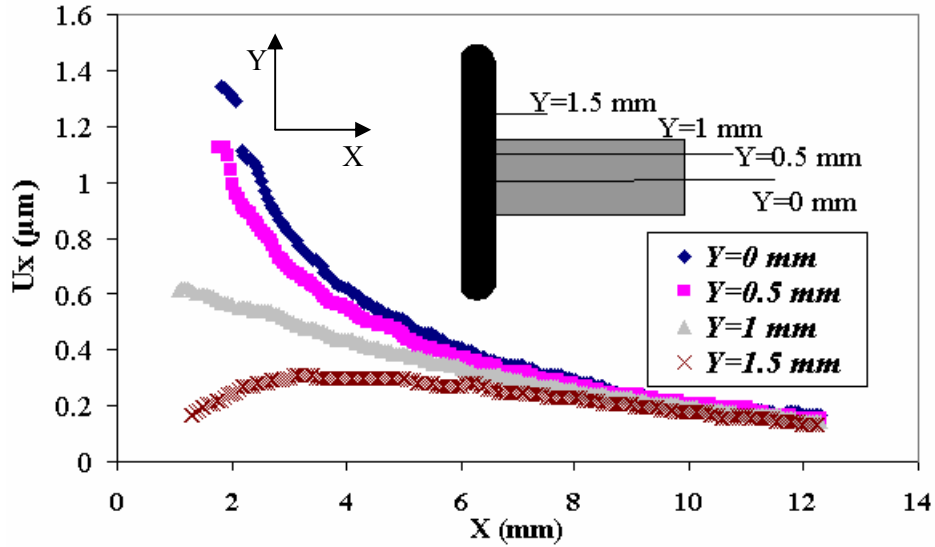


Fig [4] displacement along lines perpendicular to the groove for a machined depth of $500\mu\text{m}$

Fig.4 shows curves of the x component of displacements along 4 lines perpendicular to the groove for a machined depth of $500\mu\text{m}$. $Y=0$ represents the line corresponding to the center of the shot peened band. It can be observed that displacements decrease while Y increase.

Fringe pattern results

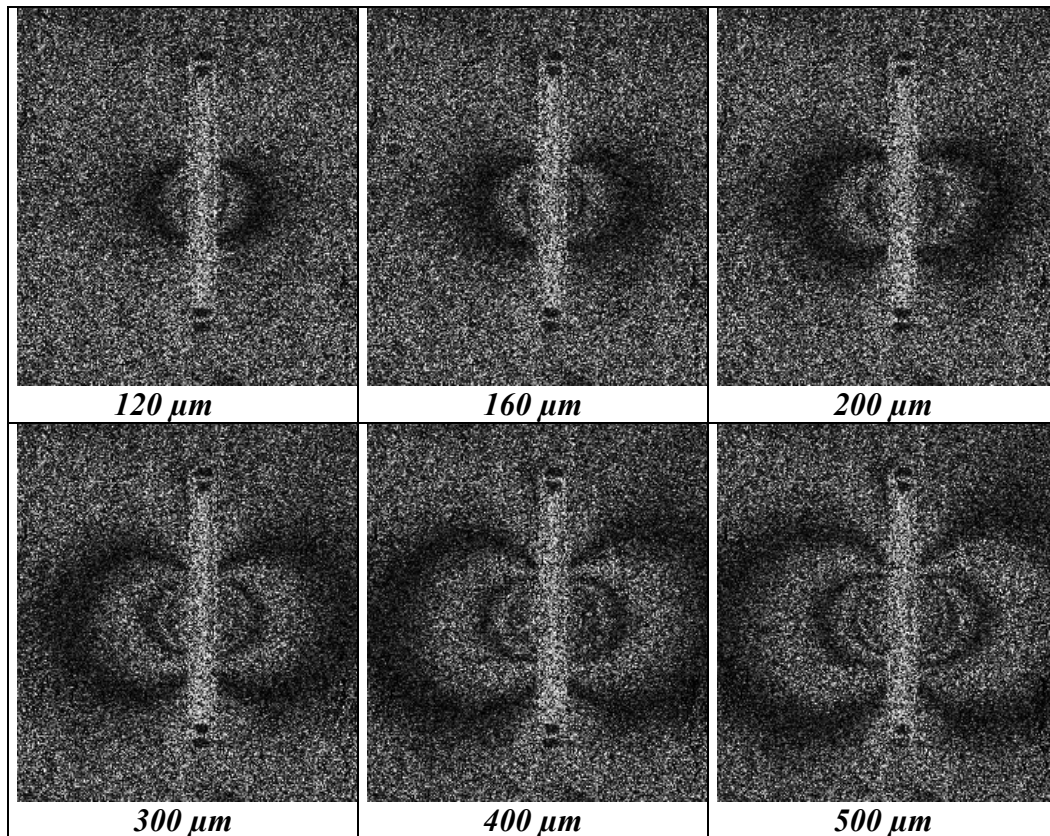


Fig [5] Images of fringe patterns obtained for each increment

Fig.5 shows the fringe patterns obtained when the groove is drilled in six increments. We can see that the number of fringes increases with the depth of the drill. It is important to precise that the fringe pattern obtained here are equivalent to those obtained using phase shifting technique [Fig.3]. The fringe order is used to determine the displacement distribution.

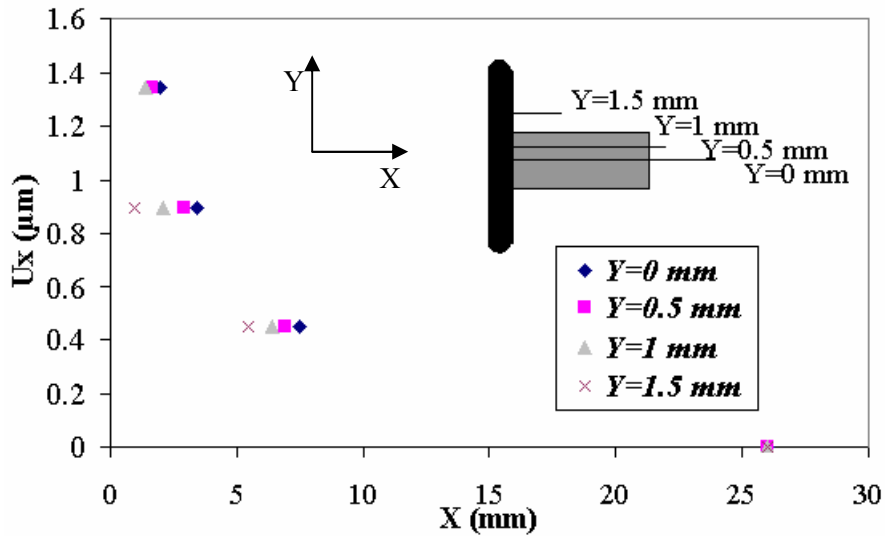


Fig [6] Displacement along groove as a function of the position y depth of 500μm

Fig.6 shows the x component of displacement for a machined depth of 500μm. Like in phase shifting, displacement is increasingly important when y decreases.

Comparison and interpretation

Fig.7 shows a good agreement between the two measurement techniques. The results found by analysing the fringe patterns [Fig.6] fit well with those obtained using phase shifting technique [Fig.4]. However the fringe pattern method is limited in the number of measurement points.

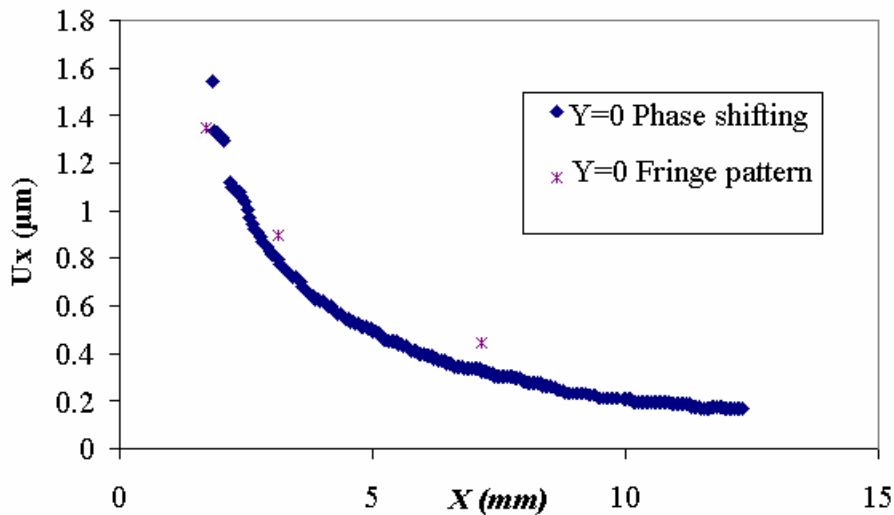


Fig [7] Comparison of displacement in the center of shot peened band obtained by phase shifting and fringe pattern

Fig.8 presents the surface displacements in the center of the shot peened band ($Y = 0$ mm), for each machined depth. We can see the evolution of displacement profile according to the depth. The displacement increases as the depth of the groove increases. It is due to the accumulation of the stress relaxation at each machining increment.

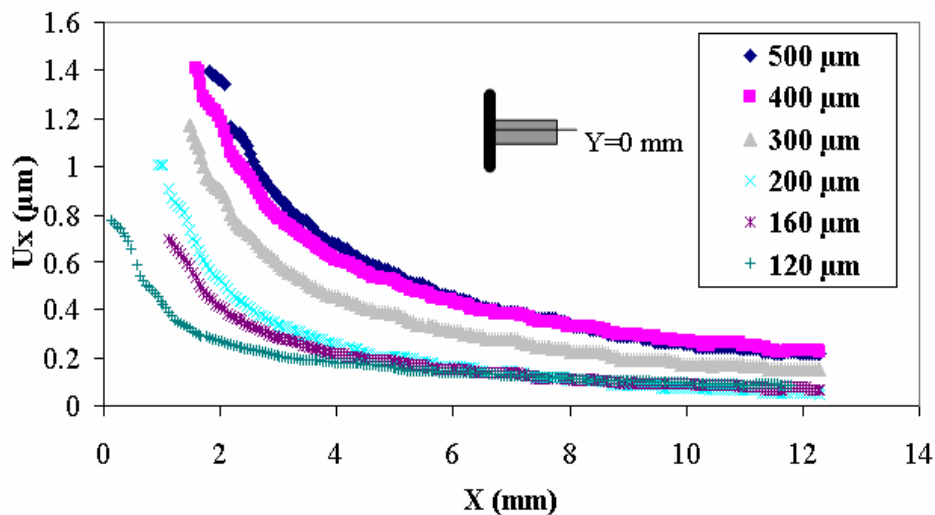


Fig [8] Evolution of displacement in the center of the shot peened band for several machined depth increments

Conclusion

A new approach in residual stress analysis based on combining an optical and a mechanical setup was proposed. The results obtained confirm the feasibility and the relevance of this approach. The originality of this technique is the possibility to measure, firstly the displacement profile in depth of the structure, and secondly the displacement field following the axis of the machined groove. This can be useful to measure the stress gradient in two directions, for instance in weld joints. In future work only the phase shifting technique will be used because it brings more information. Work is currently in progress to obtain the stress field from influence coefficients calibrated with a finite element model.

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