CONSIDERATION ON TEMPERATURE FIELDS AND INTERNAL RADIUS OF ANALYSIS IN HDM+ESPI RESIDUAL STRESS MEASUREMENTS

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Summary: *Hole drilling is the most widespread method for measuring residual stress. This method is based on the principle that drilling a hole in a material causes stress relaxation; by measuring the resulting strain it is possible to calculate the initial residual stress. Recently optical systems were introduced to replace strain gage rosette since they can provide full field measurements with high sensitivity. When using ESPI technique, the analysis area, that is to say, the portion of the image which must be used for measuring strain is defined by the operator. Proper choice of this area can be affected by many factors. In this paper, in particular, the influence of drilling rotation speed is investigated. To this scope measurements at three different speeds were carried out and for each speed the temperature field around the hole was measured by using a thermocamera.*

Keywords: *Residual stress, Hole Drilling Method, ESPI*

1 Introduction

Residual stresses (RS) are present in a material even in absence of an external load as a consequence of manufacturing processes. Due to the complexity of the processes usually involved in the production of a piece or a part, residual stress are hard to be theoretically evaluated. The most reliable approach is based upon experimental evaluation and, to this scope, a lot of different methods have been developed along years including: X-Ray diffraction, Barkhausen Noise, Raman Scattering, ecc. However, nowadays, the most commonly adopted method for measuring RS is the Hole Drilling Method (HDM), being an approach based upon the operation of drilling an hole in the material under test and measuring the on-surface deformation connected with the drilling operation. HDM itself has been greatly improved along years by optimizing the drilling procedure, the stress calculation algorithms and so on. A further promising improvement, which is under investigation in these years, is connected with the possibility of replacing strain gage rosette with optical systems for measuring the strain on the surface [1, 2]. With this approach it is possible to get high sensitivity and high resolution measurement of the strain field around the hole, greatly increasing the statistics involved in the measurement in view of the fact that each single pixel can be considered to act like an extensimeter [3, 4]. However while position of the extensimeters in a strain gage rosette is established by standards further investigations must be carried on about the influence of the distance from the center of the hole of the pixels which are used for stress calculation. To this scope, in this paper we adopted Electronic Speckle

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Pattern Interferometry (ESPI) to measure the strain field and we studied how the choice of the analysis area, including the image pixels which are effectively elaborated to measure strain, affects the final result. The influence was also studied in connection to the variation of another fundamental process parameter that is to say the drilling rotation speed. Measurements at three different speeds were carried out and for each speed the temperature field around the hole was measured by using a thermocamera, at the same time the influence of choosing different internal radius for stress calculation was studied. It was noticed that changing the speed of rotation, also the maximum temperature reached during the drilling process changed and consequently it could be supposed that also the plasticization area around the hole changes. This affects the choice of the minimum distance of the pixels from the center of the hole in order to have reliable measurements.

2 Materials and Methods

Test were performed on a Titanium grade 5 (Ti-6Al-4V) specimen (248.5 mm $\times$ 42.5 mm $\times$ 3.0 mm) which was loaded in a four-point-bending frame in order to induce a known stress state on the sample. The sample was loaded so that an unidirectional longitudinal stress field is obtained with σ_{xx} =144 MPa. To this scope it was important to guarantee that the measured stress only refers to the applied external reference load by avoiding to include any initial residual stress field. To this purpose preliminary X-ray residual stress (XRD) measurements were performed in order to asses if the as received material can be considered free from stress or it has to undergo to annealing process.

A solid state laser source was used in order to shine the sample and generate the speckle pattern which is then recorded by a CCD camera. Light diffused by the sample is made to interfere on the CCD matrix with a reference beam. Four-step temporal phase shifting algorithm is adopted in order to obtain the phase. The hole is drilled by means of a high speed turbine which is mounted on a precision travel stage. Turbine rotation ranges from 5000 to 50000 rpm and is electronically controlled. The cutter is made by tungsten coated by TiN and it has a nominal diameter d =1.59 mm.

The HDM+ESPI method was utilized to evaluate the external four-point bending applied stress (Fig. 1). An hole was drilled up to 0.40 mm depth, each step was 0.05 mm. The holes were drilled along two lines on the 248.5 mm $\times$ 42.5 mm face of each specimen (Fig. 2). The distance between the centers of the holes of each line was set to 12 mm to minimize the interaction between the holes. The two lines were located at 12.0 mm from each edge in order to minimize edge effects and have sufficient distance between the center of the holes on opposite lines. The central holes were 6 mm from the centerline of the specimen in order to have a symmetrical distribution of the holes. For each drill increment the corresponding speckle pattern was recorded at four different positions of the piezoelectric translator. These intensity maps were subtracted from the reference intensity pattern recorded on the sample before starting the drilling procedure. This operation allows obtaining fringe pattern encoding the information about the displacement experienced by the sample along the sensitivity vector. Once displacement maps were obtained a derivative filter was used to get strain maps and then integral method was used to calculate stresses. A thermocamera was also placed in front to the sample in order to record temperature field around the hole during the drilling process. Main parameters of the NECH2640 are listed in Table 1.

Table 1: Main characteristics of the NECH2640

Parameter	Value
Resolution	0.03°C
Frame rate	30 frames/s
Range temperature	-40÷500 °C

Data obtained at three different speed rotations (5000 rpm, 35000 rpm and 50000 rpm) were analyzed. The entire cycle of heating and cooling to environmental temperature takes about 6 seconds, not depending on drilling speeds and on the hole step. In order to better understand the correlation between the maximum

Figure 1: Experimental set-up adopted for the evaluation of the temperature field

Figure 2: Titanium Grade 5 Specimen

temperatures reached and the correspondent speed rotations, trends of each temperature for each step and speed rotations were plotted in Fig. 3.

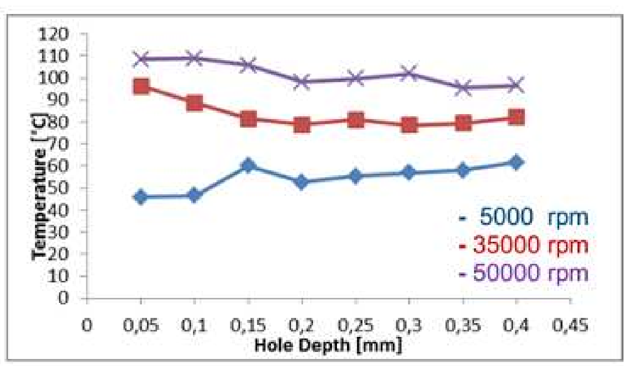

Figure 3: Temperature measured by thermocamera during the hole drilling process at different rotation speed

From Fig. 3 it is possible to infer that higher temperature, up to about 110 °C are obtained at 50000 rpm; reducing the rotation speed also temperature reduces down to about 55 °C averagely at 5000 rpm. If residual stress measurements are performed on the same Ti sample under the same level of stresses differences are observed as reported in Fig. 4. In these figure the measured stress is plotted as a function of r_{int} value ($r_{\text{int}} = R_{\text{int}}/R_{\text{hole}}$); that is to say the ratio between the hole radius and the minimum distance of the pixels used in the calculation from the center of the hole.

It can be observed that while at low rotation speed the measurement of the stress is almost independent on the r_{int} value, a strong dependence appear higher rotation speed. This dependence can partially be explained in view of the higher temperature reached at higher speed affecting the extension of the plasticization zone. Furthermore fine dust is produced and deposited around the hole edges at higher rotation speed affecting the final result.

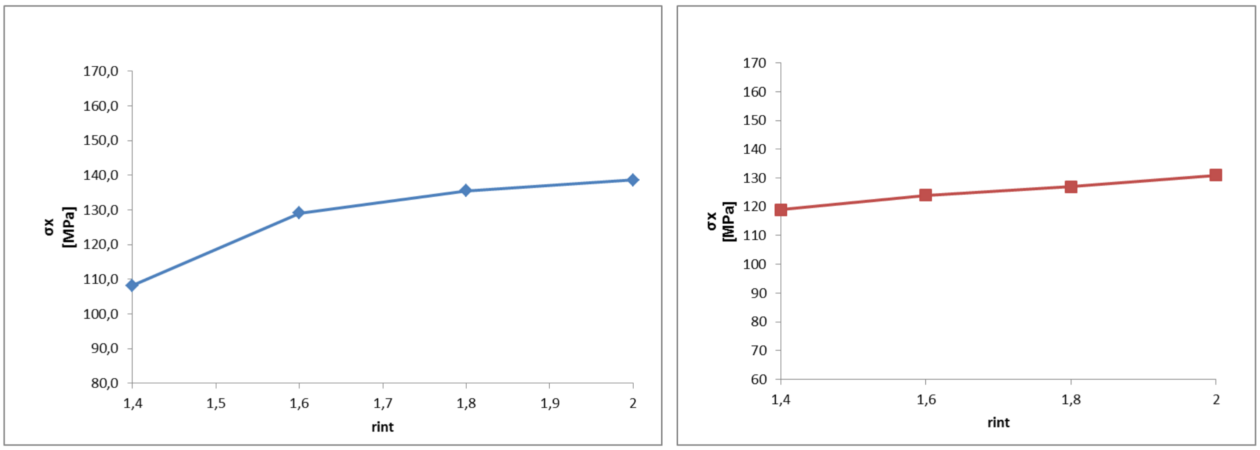

Figure 4: Measured stress on a calibrated Ti sample as a function of the r_{int} parameter, (a) 50000 rpm, (b) 5000 rpm

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