Processing speckle images to improve quality of Residual Stress measurements by HDM-ESPI

C. Barile, C. Casavola, G. Pappalettera, C. Pappalettere

Abstract— Industrial processes which lead to the creation of the final components are potential sources of residual stresses. Any kind of manufacturing process, in fact, as welding, forging, casting etc. introduces a given stress state in the component that it is not easy to be evaluated by numerical approach. Many experimental techniques have been developed along the years in order to have an accurate evaluation of the residual stress state. Equipment and techniques have strongly evolved along the years and new approaches are also taken into account currently. Among the innovative procedures for residual stress evaluation, one of the most interesting one is HDM-ESPI that can be considered a direct evolution of the well consolidated hole-drilling method. This is a powerful approach consisting in detecting, by the Electronic Speckle Pattern Interferometry the displacement field generated around the drilled hole. This means that strain gage rosette is replaced by an optical approach. Of course the quality of the recorded images can affect the reliability of the measurement. In this paper some considerations on pixel quality are presented along with some indications about the proper choice of the internal radius of analysis. It will be demonstrated that, from a practical point of view, the quality of the image can be diminished by the production of some fine dust that sticks to the surface altering the speckle pattern. As a consequence it will be seen as a proper choice of the pixels to be used for residual stress evaluation can affect the final quality of the measurement.

Keywords— Residual Stresses, Hole-Drilling, ESPI

I. INTRODUCTION

RESIDUAL stresses (RS) are present in a material even in absence of an external load as a consequence of manufacturing processes [1]. Nowadays, the most commonly adopted method for measuring RS is the Hole Drilling Method (HDM) [2], 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 [3]. A 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 [4]. 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 a strain gage[5,12]. When performing this kind of measurements the operator is free to set the position of the circular crown including the analysis area. This is the area including the pixels whose information will be used to extract the displacement information and the consequent stress calculation. However the quality of the information connected with each pixel cannot be considered uniform. For example, different points on the surface can present different reflectivity and this can require the adoption of preliminary spray painting of the surface. Furthermore some dust resulting from the drilling process can be deposited around the hole during the drilling process. In this paper we will show how this effect depends on the drilling speed and how this affects a proper choice of the internal radius of analysis.

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II. MATERIALS AND METHODS

Test were performed on a Titanium grade 5 (Ti-6Al-4V) specimen (248.5 mm x 42.5 mm x 3.0 mm) which was loaded in a four-point-bending frame (Fig.1) in order to induce a known stress state on the sample.

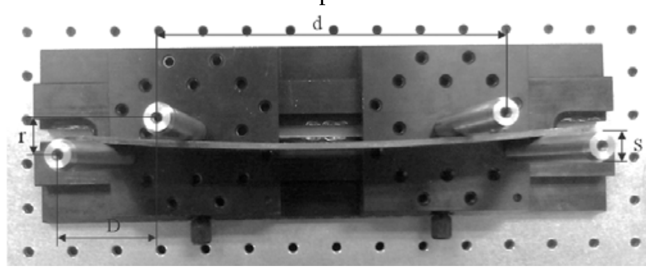

Fig. 1 Upper view of the clamping system

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. Two different levels of the turbine speed were tested: 5.000 rpm and 50.000 rpm. The drill bit is made by tungsten coated by TiN having a nominal diameter of d=1.59 mm. The HDM+ESPI method was utilized to evaluate stress in the sample. A hole was drilled up to 0.40 mm depth, each step was 0.05 mm. Both the drilling speed and the position of the turbine are electronically controlled. After each drilling bit increment the turbine is moved far away so that it doesn't obstruct the field of view of the camera. A picture of the system including the ESPI system and the drilling apparatus is shown in Fig.2

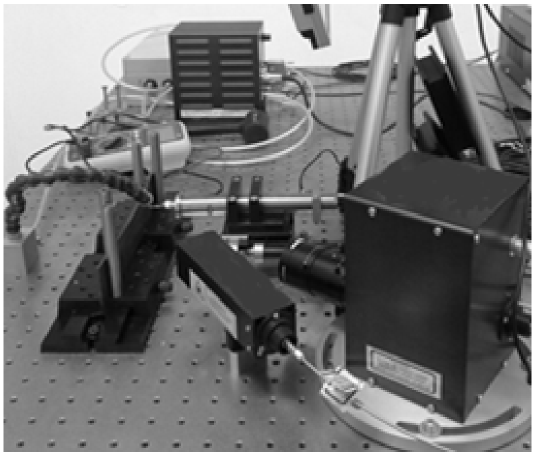

Fig. 2 Experimental set-up adopted for HDM-ESPI evaluation of RS

III. RESULTS AND DISCUSSIONS

In Fig. 3 an example of correlation speckle fringes is displayed. Each fringe represents points with the same displacement in the direction of the sensitivity vector. In Fig. 4 an image of the drilled hole, taken by the CCD camera, is shown. In the figure it is also reported the indication about the internal and external radius of analysis. Only pixels included in the indicated circular crown are used for residual stress calculation.

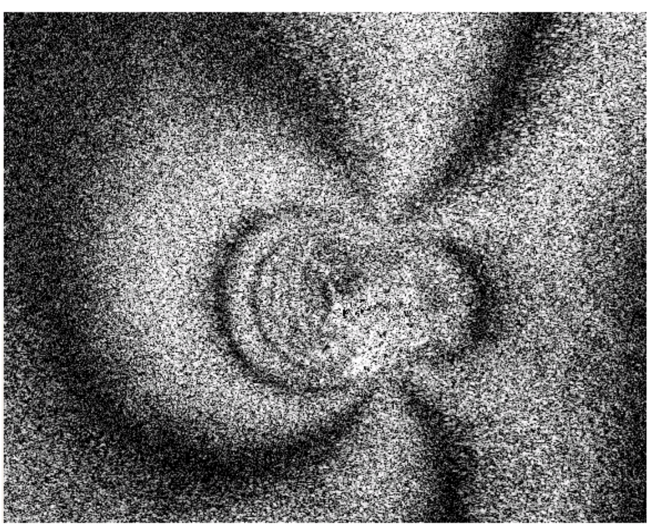

Fig. 3 Exemplary fringe pattern recorded during the drilling process. Fringes represents the lines of iso-displacement with respect to the direction of sensitivity of the interferometric system

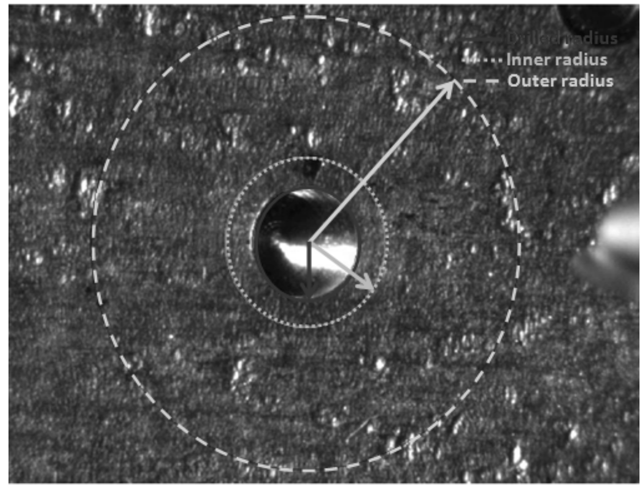

Fig. 4 Screenshot of the area of analysis included between the outer circle (dashed line) and the inner circle (dotted line). The solid line identifies the drilled hole.

In Figs. 5 and 6 results of the stress measurements are presented for the two investigated rotation speed. In particular it is possible to observe that a strong variation in the calculated stress is observed for the case of 50000 rpm if the internal radius of analysis is reduced. This means that including more pixels near the edges of the drilled holes introduces an error in the measurement. Some previous experiments [13] proved that there is no significant difference in terms of thermal input corresponding to the different experimental conditions. This indicates how that kind of difference cannot be reconnected to different plasticization around the hole. A possible explanation for this could be reconnected to different quality of the speckle image in the two different conditions.

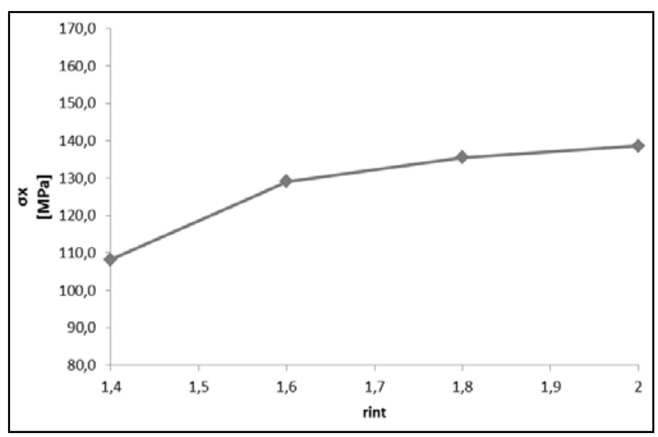

Fig. 5 Calculated σ_x stress as a function of the internal radius of analysis. Drilling Rotation speed: 50000 rpm

This behavior can be explained if the quality of the pixel is evaluated. Fig.7 and Fig.9 show that in both cases the ratio of bad pixel increases approaching the edges of the hole. This effect is more evident in the case of high speed drilling due to the fact that a bigger amount of fine dust is produced in the process which stick to the surface, in particular near the edges of the hole, altering the measure.

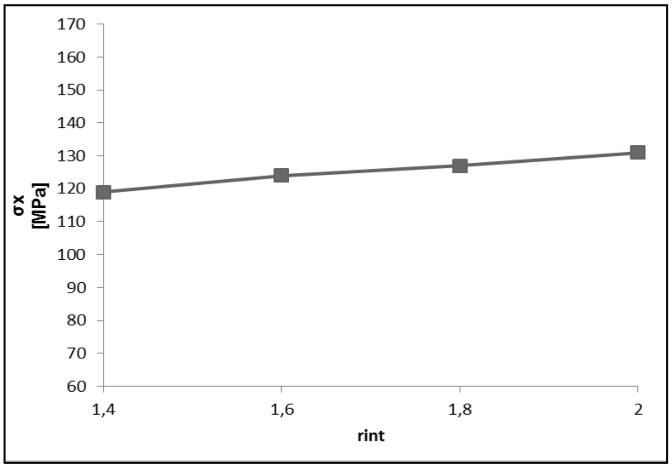

Fig. 6 Calculated σ_x stress as a function of the internal radius of analysis. Drilling rotation speed: 5.000 rpm

This observation is dependent on the machinability of the material as well as on the drilling process itself. In particular the size of the produced chips can be determinant. If the chip size is big it tends to fall down after the drilling process so that it doesn't disturb the measurement process. If the chip size is small it sticks to the sample so altering the surface of the sample. In this cases the phase recorded per each pixel doesn't depend on displacement of the point imaged at that pixel but it is completely altered by the presence of dust. This hypothesis was tested by evaluating the pixel quality.

In order to do this saturated pixel, low visibility pixel were calculated. In Figs. 7 and 9 it is shown how the bad pixel ratio change as a function of the radius of analysis while in Figs. 8 and 10 the corresponding phase maps are displayed. It is possible to observe that the bad pixel ratio increases more rapidly, by decreasing the internal radius of analysis, in the case of hole drilled at 50000 rpm. This introduces the presence of phase errors as it appears evident by analyzing the calculated phase maps.

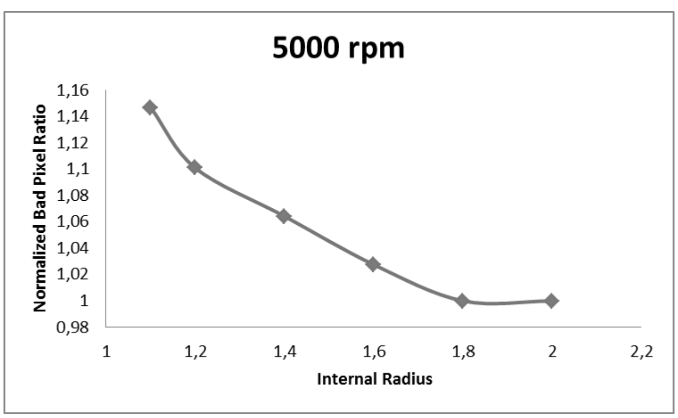

Fig. 7 Bad pixel ratio as a function of the internal radius of analysis. Drilling rotation speed: 5000 rpm..

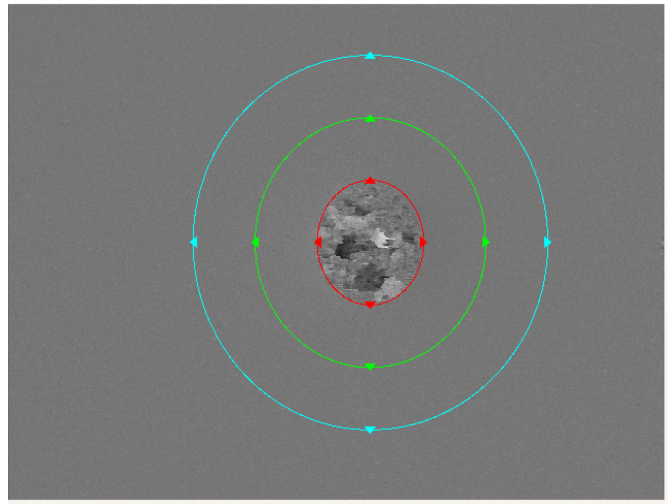

Fig. 8 Calculated phase map for a hole drilled at 5000 rpm

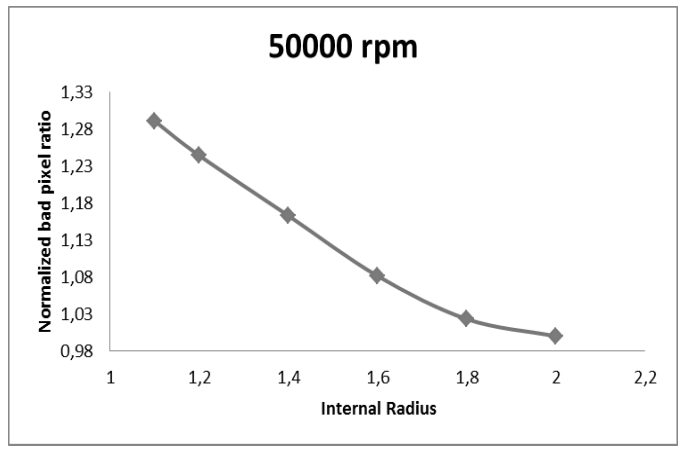

Fig. 9 Bad pixel ratio as a function of the internal radius of analysis. Drilling rotation speed: 50000 rpm.

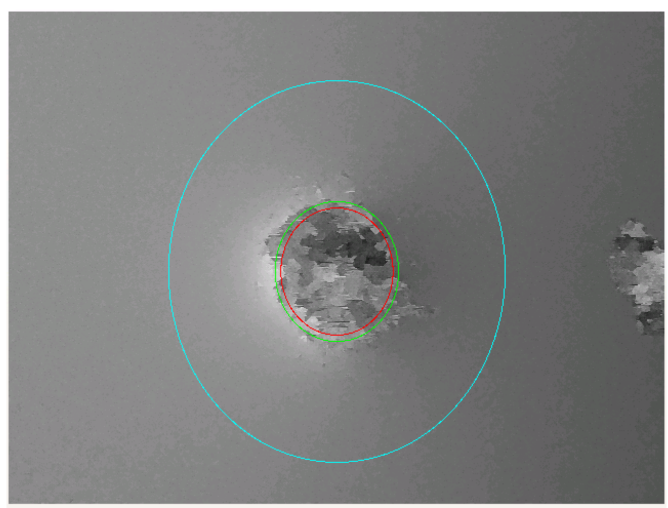

Fig. 10 Calculated phase map for a hole drilled at 50000 rpm

IV. CONCLUSIONS

In this paper it was observed that final accuracy of residual stress measurement by hole drilling combined with electronic speckle pattern interferometry depends, among other parameters also on the quality of the image. Keeping unchanged all the other parameters that can affect fringe quality as laser quality, reference to illumination beam intensity and so on, still the image quality can be dependent upon process parameters. In fact, formation of dust can alter the surface of the sample and locally destroy correlation among speckles. For Ti grade 5, specifically, it was found that using lower rotation speed increase quality image. However it should be taken into account that using a lower speed cannot be considered a general good practice because this can affect, on the other side, the quality of the drilled hole. A good approach to have a good drilled hole beside good displacement map to be computed to evaluate residual stress relies on evaluating pixel quality and to eliminate them from calculation. Increasing the internal radius of analysis can be an easy way to cut off from calculation pixel of bad quality. However, as a future work it would be interesting to introduce threshold of acceptance in order to select pixels that should be processed for stress evaluation.

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