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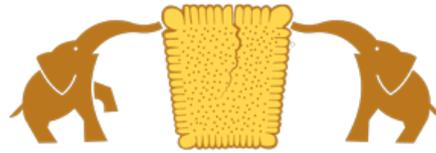
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Is-it possible to measure accurate strains field by 2D DIC methods at high temperature ?

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Abstract — Although Digital Image Correlation method is relatively mastered at room temperature, it is more complex to implement this method at temperatures from 500°C to 800°C. The aim of this study is to develop new tools and algorithms to improve DIC accuracy and precision in this temperature range. New methods to implement speckles and new algorithm to decrease errors due to mirage effect are developed. These improvements will be used for aeronautical applications.

Keywords — DIC, High temperature, Speckles, Strain measurement, Mirage effect

Introduction In aerospace industry, the final shape of some complex parts, e.g. pylons or engine air inlet made by Ti-6Al-4V (TA6V) titanium alloy sheet, are manufactured by hot forming process. To control the final geometry after forming operation and/or to improve the accuracy of the Finite Element Method (FEM) model during the cooling phase, an access to continuous full-field kinematic measurement would be appreciated. One solution is to use Digital Images Correlation (DIC) method. Although this method is relatively mastered at room temperature, it is more complex to implement at temperatures from 500°C to 800°C. This is due to two main factors: the mirage effect (phenomena of refractive index gradient) and the loss of image contrast. Moreover, "Classical" Speckles, usually made by painting do not resist to this temperature range and large strain. The aim of this study is to develop new speckle fabrication techniques, experiment set up and algorithm to improve DIC accuracy and precision in temperatures from 500°C to 800°C.

Methods Methodology was developed in three parts: (i) to create speckles that hold high temperatures and large strain, (ii) to characterize mirage effect and (iii) to develop new post processing algorithm to improve DIC measurement in temperatures from 500°C to 800C.

First, six different techniques were tested: Painting, Direct anodisation, Inverse anodisation, Laser engraving, Combination of laser engraving and anodisation, Combination of laser engraving and painting. These speckles were produced systematically from a numerical speckle that respects some criteria: speckle size, distance between speckle patterns, speckle randomness and speckle density [1, 2]. The speckle quality was evaluated by comparing values of some factors:

- the integrity of speckles produced by various techniques from the numerical one. This factor was evaluated by speckle morphology parameters: the speckle density (ratio of the number of 1-bit pixel and total number of pixels in the Zone of Interest (ZOI)), the speckle size and the speckle distance.
- the image contrast: the Mean Intensity Gradient (MIG) [6], the Shannon Entropy [5] and the percentage of saturate pixels (defined as the ratio of the saturate pixels over the total number of pixels of the ZOI)

Secondly, to characterize the influence of the high temperature to the strain measurement, images at different time were captured on the ZOI of a tensile-test specimen. The method is based on the principle of the BOS method [4]. No load was applied during this time. The mechanical strain measured by DIC

should be equal to 0. All strain measured by DIC (VIC-2D, V6, Correlated Solution, USA) are equivalent to "false" strain due to experiment errors.

To finish, a new post-processing algorithm using Gaussian low-pass filter is develop to decrease the mirage effect. Hypothesis is that mirage effect create errors at high frequencies on the image [4]. Gaussian filter allows to separate mechanical strain appeared at low frequency and error due to mirage effect mainly caused by convection flow in the oven which appears at high frequency. The parameters of this filter (size r and σ) was optimized thanks to the "false" strain measured in the static condition.

Results Firstly, appropriate speckles are created regarding requirements to obtain a "good" speckle at temperatures from 500C to 800°C. At 600 °C, the speckle created by combining laser engraving and anodisation presents the best quality with a density of 0.3, a MIG value of 16.3 and low percentage of saturate pixels of 0.04%. At 700°C, the speckle made by combining laser engraving and painting presents the best quality with a density of 0.29, a MIG value of 9.5 and 0.02% of saturated pixels. The speckle made by combining laser engraving and anodisation resists to a large strain of 2.0 while the speckle made by laser engraving and resists to a strain of 0.2.

Figure 1a, 1b and 1c show the longitudinal strain fields measured at zero load at three different times. It is observed that the strain field is heterogeneous. It is due to the convective flow present between the hot object and the camera. Figure 1d and 1e show the longitudinal strain fields measured by DIC before and after correction by Gaussian low pass filter. After the correction, the strain field is more homogeneous. This filter permits to improve the accuracy of the strain field measured at high temperature.

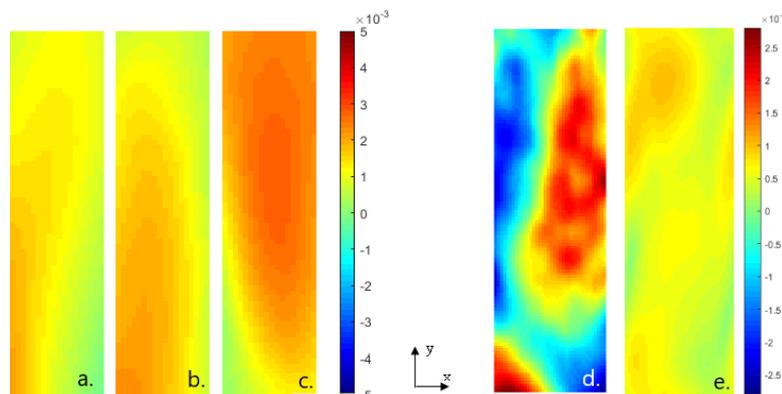


Figure 1: a, b and c: Longitudinal strain fields measured by DIC at three different times at static condition for zero strain, d: Longitudinal strain field measured by DIC at 600°C during a tensile test, e: Same longitudinal strain field after a correction with the Gaussian low pass filter (radius $r=5$, $\sigma=2$)

Discussion and Conclusion This study is a first step to improve DIC measurement at temperature from 500°C and 800°C. "Good" Speckles can be obtained to perform strain measurements at high temperatures. Mirage effect creates "false" strain at static condition. Preliminary results show that Gaussian filter can be a solution to minimize this error. Future studies will use this new methodology to characterize mechanical properties of materials at high temperature or to follow strain field during cooling phase. More studies must be perform to extend the temperature range.

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