An optical strain gage for full-field measurements

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Abstract. Full-field measurement methods allow their users to capture displacement/strain fields during experiments. They are well established in the experimental mechanics community. Most of the time, these measuring methods require patterns to be deposited on the specimen before test. These patterns are either random for Digital Image Correlation (DIC) or periodic for spectral techniques such as Localised Spectrum Analysis (LSA). Regarding the metrological performance, it has been demonstrated that the optimal pattern is a checkerboard because it maximizes image gradient. However, using such a pattern in practice is complex since its deposition remains somewhat tricky. Recent studies show that it is possible to use a laser engraver to print black dots on a specimen covered with a thin layer of white paint. The present contribution proposes to push this solution forward by printing a fine checkerboard pattern on a thin polymeric film and then gluing it on the specimen surface. This allows the separation of the manufacturing process of an optical strain gage on the one hand, and its use on the other hand, thus facilitating the spread of this strain measuring tool in the experimental mechanics community. The manufacturing and bonding processes of this new strain gage are described. It is then applied on an example to demonstrate its ability to capture strain fields featuring fine sharp details.

Possible Sessions

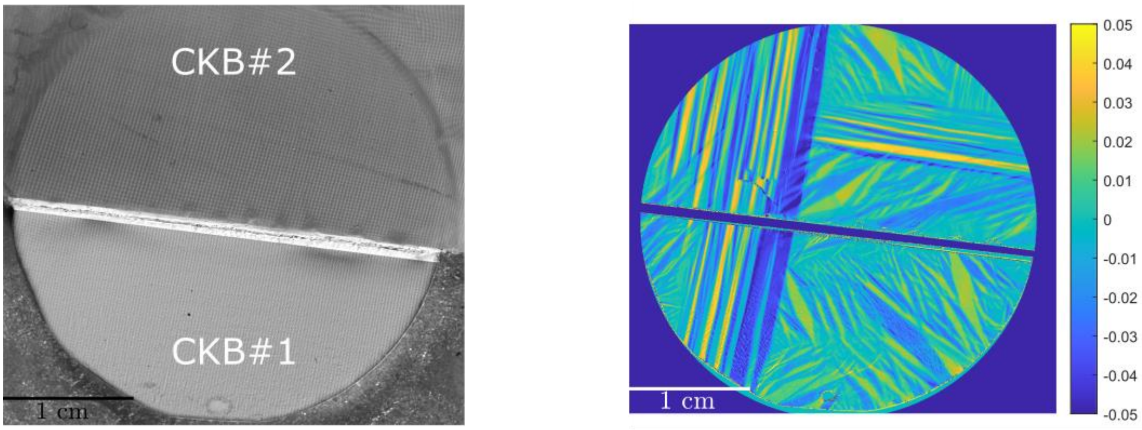
16. Novel Experimental Techniques, 19. Optical and DIC Techniques

Introduction

Full-field measurement techniques are now common in experimental mechanics. For in-plane strain and displacements measurements, the use of periodic patterns such as checkerboards leads to the best metrological performance [1]. To process images of such patterns, a solution is to minimize the optical residual in the frequency domain [2]. This leads to a quasi-direct link between the sought displacement and the phase change of the periodic pattern between the current and reference configurations. The so-called Localized Spectrum Analysis (LSA) is used to extract the displacement and strain fields from the checkerboard pattern images discussed in this study. A major hurdle is to deposit the tiny dots forming the checkerboard on the surface of the specimen to be tested. A strategy, recently presented in [3], consists to directly engrave the pattern on flat surfaces with a laser engraver, the surface being spray-painted in white beforehand. Checkerboards with squares as small as 50 µm were engraved [3]. Further developments then enabled to reduce this size to 30 µm [4]. However, the major disadvantage of this solution is that a laser engraver is quite expensive (55~keuros minimum), which is a barrier to the diffusion of LSA. This work proposes to improve this solution by printing such a pattern on a thin polymeric film, and then gluing it on the specimen surface, as routinely done with standard electrical strain gages. This allows to separate the manufacturing process of such an optical strain gage and its use, thus allowing to spread this developed strain measuring tool in the experimental mechanics community.

Methods

A 25 µm thick polyimide film manufactured by DuPont was chosen as it is the same as the film used to produce electrical strain gages. The film supplied by ADDEV Materials, Saint-Chamond, France, is white in its bulk. The checkerboard was directly engraved on the film, following the procedure described in [3]. Then, the engraved film was bonded on the specimen using a procedure similar to that used for bonding strain gages. In particular, a cyanoacrylate glue suitable for classic electric strain gages was employed. To assess the ability of this new optical strain gage to capture strain fields, it was applied on a disk specimen of diameter 3.3 cm, made of a single-crystal of $CuAl_{13.9}Ni_{4.6}$ (wt.%) shape memory alloy (SMA) subjected to temperature-induced phase transformation. When cooled to nearly 0 °C, martensite microstructures are formed within the sample. They remain unchanged when the sample returns to room temperature [4]. These microstructures create heterogeneous strain fields with sharp details and highly localized gradients. For comparison purposes, only half of the specimen was instrumented using the proposed method (CKB #2), while the other half was instrumented by first spray-painting in white and then engraving the pattern (CKB #1), by using the procedure described in [3]. The border between the two types of patterns was placed perpendicularly to a set of parallel martensite bands in order to examine if the strain measured within them remains constant when changing the type of marking. Fig.°1–(a) shows a picture of the SMA sample marked with both methods.

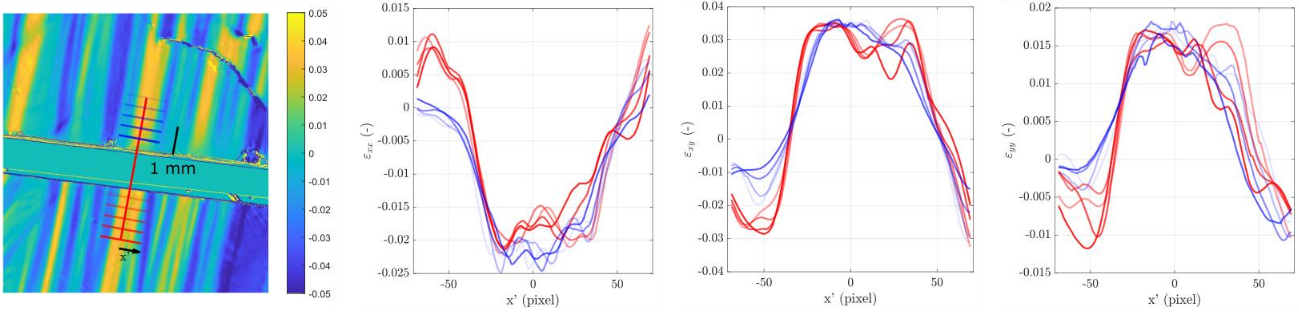


(a) (b)

Figure 1: (a) Picture of the SMA sample marked with CKB #1 and CKB #2. (b) Typical ε_{xy} strain map.

Results

Two sets of images were taken in the reference configuration. The settings (light, aperture) were optimized for CKB #1 in the first set, and for CKB #2 in the second set. Similar procedure was followed when the specimen was in the deformed configuration. The strain fields obtained on both halves were then merged to form unique strain fields over the whole specimen surface. Fig.°1-(b) shows a typical ε_{xy} strain map, and Fig.°2-(a) a close-up view of the ε_{xy} map obtained with both markings where y is the vertical direction. Overall, no real difference can be noticed between the global appearance of the maps obtained with both markings. The strain magnitudes are similar. Several cross-sections were then analysed in order, to check along a given martensite band if the amplitude of the strain components changes or not when crossing the border between each pattern. These cross-sections are plotted in Fig.°2-(b)(c)(d). No attenuation of the signal is observed when going from the red to the blue curves for the three strain components.



(a) (b) (c) (d)

Figure 2: Analysis of strain distributions measured. (a): Close-up view of the ε_{xy} strain map with the location of the line along which the cross sections are plotted. (b)-(d): Strain profiles. Red: CKB #1. Blue: CKB #2.

Discussion and Conclusion

A procedure for engraving checkerboard patterns on polyimide films and bonding them on flat specimens is proposed in this work. A challenging testing configuration giving rise to heterogeneous strain fields with sharp localizations was used. It is shown that no significant difference in the strain maps is observed when comparing results obtained with the present gage and the classic printing procedure used so far. This illustrates the fact that this optical strain gage can be an ideal tool for analyzing heterogeneous strain fields in experimental mechanics. Printing this type of gage would help spread and popularize optimal patterns for full-field strain measurements in experimental mechanics, and contribute making such measurements more reliable and reproducible. More details concerning this optical strain gage can be found in [5].

References

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