Regularized InfraRed Image Correlation Applied to Laser-Induced Thermal Shocks

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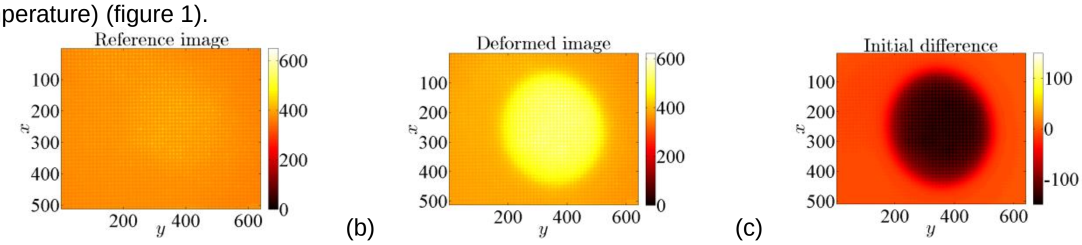
Abstract

The thermomechanical behavior of a stainless steel undergoing thermal shocks is investigated with an infrared (IR) camera. The temperature and kinematic fields are determined simultaneously exploiting only IR frames. The thermal loading is imposed with a laser, which gives rise to very high local digital level variations. This effect is addressed thanks to a regularized infrared image correlation (R-IRIC) technique, which accounts for brightness and contrast variations. The resulting digital level residuals are reduced from 54% down to less than 1% of the dynamic range.

1. Introduction

The thermomechanical behavior of a stainless steel subjected to thermal shocks is investigated with an infrared (IR) camera. The characterized sample is a polished $50\times50\times10$ mm^3 parallelepiped made of 316L(N) austenitic stainless steel. In order to measure displacement fields by image correlation, a random pattern (e.g., pre-oxidation or laser engraving [1]) is applied onto an initially polished surface of the sample. A pulsed laser (TruPulse 156 manufactured by Trumpf, λ = 1064 nm) is used to induce cyclic thermal shocks in the center of one of the two largest faces of the samples [2]. A focussing optics delivers a top-hat power density whose diameter is 5 mm. Due to a relatively low absorptivity of the polished surface, the beam is inclined in order for the reflected beam to be collected by a calorimeter. An infrared camera (x6540sc manufactured by FLIR, definition: 640 x 512 pixels, λ = 3999 – 4001 nm) with a high magnification lens is used to measure simultaneously the displacement and temperature fields [3]. The applied thermal shock induces very high local variations of the digital levels of subsequent pictures (in this paper, Digital Level=Temperature) (figure 1).



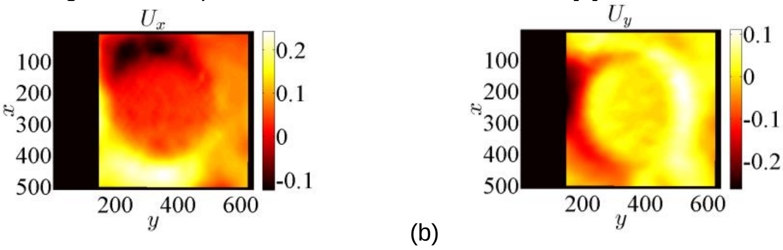
(a) (b) (c)

Fig 1: Reference (a) and deformed (b) images in absolute temperature. (c) Initial correlation residuals (RMS average: 54%)

In this work it will be shown how such a situation can be addressed for image correlation purposes without any additional experimental steps [3] or any a priori image corrections [4]. The R-IRIC procedure is implemented in a digital image correlation (DIC) code where an elastic regularization is implemented [5] and it includes specific regularized brightness and contrast corrections. It has already been shown that this technique is well suited to visible light camera images, allowing for the measurement of subpixel displacement fields during laser shocks [6].

2. Preliminary results

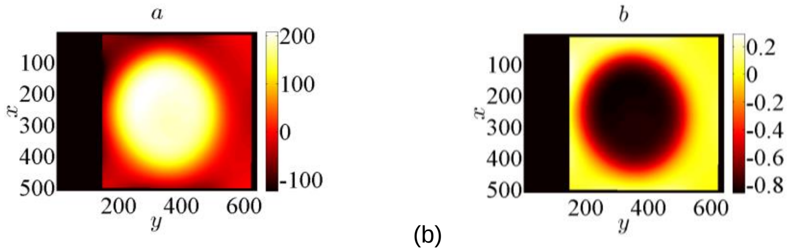
In figures 2 and 3, the displacement and temperature fields obtained at the end of a thermal shock are shown when measured via R-IRIC. These results have been obtained with a 'Top-Hat' laser from 400°C.The displacement fields correspond to a biaxial loading state as expected from numerical simulations [6].



(a) (b)

Fig 2: Displacement fields at the end of a thermal shock expressed in pixel. (1pixel=15μm)
(a) Vertical U_x and (b) horizontal U_y components

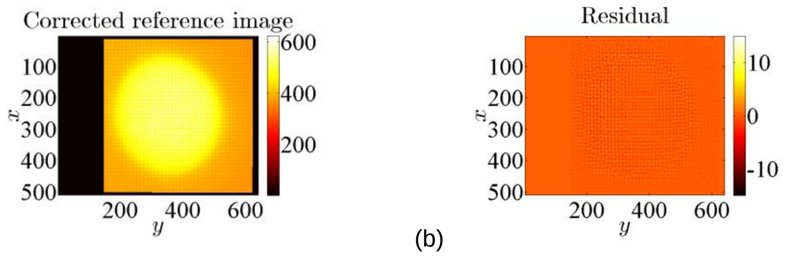
The brightness and contrast fields determined with R-IRIC (figure 3) reflect the expected temperature field produced by the laser. In particular, a difference of temperature of 250°C between the center of the impacted disk and the surrounding is well captured. It is to be noted that the local emissivity variations due to the surface speckle necessary for DIC are no longer visible because of the introduced regularization.



(a) (b)

Fig 3: Brightness (a) and contrast (b) fields

The digital level residuals (i.e., the difference between the corrected deformed image and the reference image) are initially as high as 54% of the dynamic range. They are cut down to 0.93% after the second iteration and 0.89% at convergence. The residuals are mostly due to high local variations of digital levels and they vanish after their first correction using an affine rescaling of digital levels [7].



(a) (b)

Fig 4: (a) Corrected reference image and (b) residuals map (RMS average: 0.89%) at convergence (to be compared with figure 1(a) and (c) respectively)

The displacement results are quite comparable to the measurements obtained with the synchronized visible light camera, which is not disturbed by the very high local digital level variations induced by heating. The code has also been tested with numerical test cases and provided concluding results.

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