A 3D-DIC Method for High Temperature Application

M van Rooyen[1a] and T.H. Becker[2]

[1, 2]Department of Mechanical and Mechatronic Engineering, Stellenbosch University, South Africa

[a]melzvanrooyen@gmail.com

Abstract. The experimental design for measuring full-field creep strain at elevated temperatures using 3D Digital Image Correlation (3D-DIC) is presented. This method addresses the challenge of suppressing black-body radiation and maintaining speckle pattern contrast through the careful selection of white illumination and colour filters. Furthermore, a procedure for the application of a heat-resistant coating capable of withstanding deformation is discussed. By conducting high temperature tensile tests on a Gleeble thermo-mechanical simulator, the system is tested for deformation measurement up to 900°C. The performance of the methodology at extended periods of time is proven to make it suitable for accelerated creep tests at 600°C.

Introduction

The reliability of power stations is mostly governed by the lifetime of critical components, such as steam pipework systems, that are exposed to elevated temperatures. Integrity assessments of these systems require measurement of high temperature mechanical behaviour as well as creep properties of the pipe material, particularly across welded joints. Digital Image Correlation (DIC) is non-contact method capable of measuring strain distributions and resultant material properties by comparing image recordings of a random speckle pattern on the deforming sample surface [1]. However, the application of DIC at elevated temperatures is hampered by surface radiation and oxidation together with the long term integrity of the speckle pattern coating material [2]. These factors deteriorate image quality by affecting the speckle pattern contrast and intensity distribution. Although methods have been developed that successfully measure thermal strains at temperatures of over 1000°C, creep strains have only been determined at a relatively low temperature of 545°C using 2D-DIC [2-5]. This methodology involves measuring strains over 600°C with *in situ* 3D-DIC and a Gleeble thermo-mechanical simulator during tensile tests. The method is shown to provide deformation maps for tensile tests conducted up to 1000°C.

Experimental Methods

Thermo-Mechanical Setup. Specimens of AISI 1040 steel are resistance heated in a Gleeble 3800 thermo-mechanical testing system by controlling a current under feedback control from a K-type thermocouple located at the specimen centre. The surface temperature drops in a parabolic fashion along the axial length from the control thermocouple to the water-cooled copper grips that secure the specimen ends. Three additional thermocouples placed along the length of the specimen reveal that the temperature drops by 4% within 2.5 mm of the sample centre. In order to prevent oxidation and the distortion effects of heat haze, testing was conducted in a vacuum chamber [3]. Uniaxial tensile tests are performed from 600°C to 1000°C, whereas a load-controlled tensile test was performed at 600°C for one hour using the same setup.

Speckle Pattern Preparation. In order to ensure stable adherence of the coating to the specimen, a surface preparation method was developed. The surface is successively ground with 220, 500, 800 and 1200 grit sand paper, after which it is polished with a 9 µm and then a 1 µm diamond suspension. The polished surface is then over-etched with Nital in order to create microscopic valleys for the entrapment of the paint liquid. A speckle pattern was generated on the sample surface by applying VHT FlameProof Flat White background coat with Flat Black speckles. This paint is rated to 1100°C and has ductility comparable to steel due to the amorphous precipitated silica and titanium dioxide mixture in the white base coat. This makes the pattern less likely to deteriorate at larger deformations [2].

Machine Vision System. Digital images of the sample surface are captured through the chamber viewing window using two LaVision Imager E-lite 5M cameras with a 2456 x 2058 pixel, 12-bit charge-coupled device (CCD) chip. A field of view of about 47 x 60 mm is achieved with TECHSPEC 75 mm Double Gauss macro lenses, resulting in a pixel size of about 19 µm. Post-processing was done using LaVision DaVis software that correlates image subsets using the zero-normalised Newton Raphson algorithm.

Illumination and Filters. As the surface temperature of the specimen reaches 600°C, the intensity of the emitted short wavelength light (less than 600 nm) increases. Image saturation occurs when the radiated light over-intensifies the speckle pattern. The emitted light is minimised by illuminating the surface with two white 20W LaVision LEDs with a high correlated colour temperature of 6500 K, giving it a high blue (440 nm) component within the spectral response of the Sony ICX625 camera sensor. A Hoya B-440 colour filter is then used to bracket the emitted and reflected light within the LED wavelength band.

Results and Discussion

Effect of Illumination and Filters. A comparison between the surface radiation at various temperatures using the blue filter is shown in Fig. 2 for a 5 x 15 mm area. At 1000°C, the image saturated until the speckle pattern was no longer visible. By using a green filter (Hoya G-533) together with the blue filter, the emitted radiation is greatly reduced. For improved results, however, blue LED illumination is required.

Deformation Calculation. A DIC evaluation was done with subset sizes of 60 x 60 pixels with a step size of 20 pixels. The deformation maps for the specimen subjected to a tensile test at 600, 800 and 1000 °C is also shown in Fig. 2 and indicates a displacement that varies linearly along the tensile axis, which is in agreement with uniaxial tension. Furthermore, it was found that the quality of the speckle pattern is preserved well enough for deformation mapping at extended periods of time at 600°C. However, the paint began to flake off after 57 min of testing, indicating that more focus should be placed on the surface preparation step prior to coating.

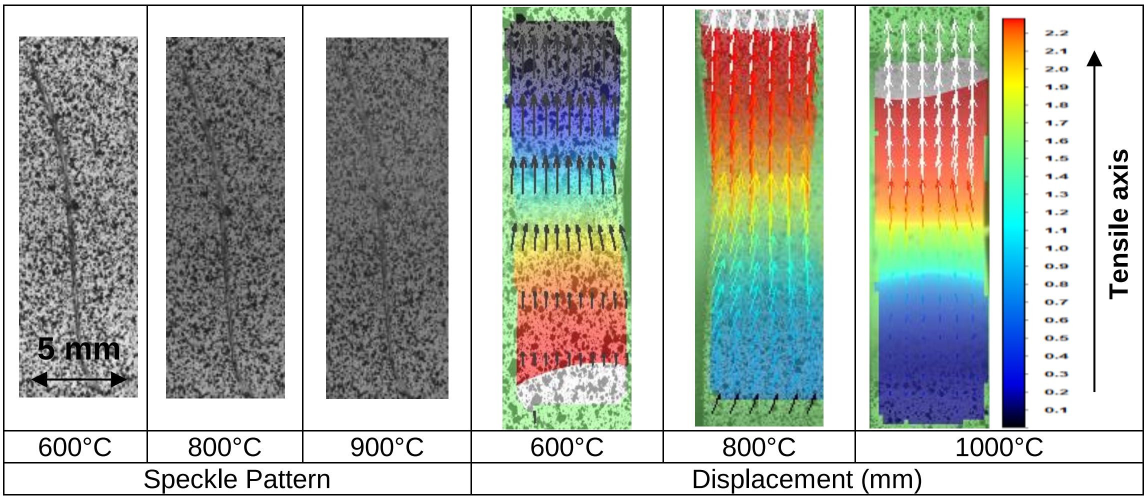

Figure 1: Comparison of speckle pattern contrast at various temperatures as well as deformation map in the tensile direction

Conclusion

A method of obtaining quality images at high temperatures for full-field deformation mapping using 3D-DIC is presented. Surface radiation is suppressed by combining white illumination with a blue imaging filter. At temperatures approaching 1000°C, a combination of green and blue filters is required to reduce image saturation. A stable speckle pattern is obtained by subjecting the specimen surface to a grind, polish and etch routine before applying high temperature paint. However, the speckle pattern began to fail when exposed to 600°C for an extended period. This indicates that a better surface preparation technique and more durable coating material is required for longer tests, such as accelerated creep tests. The current setup has been shown to be viable for measuring tensile deformations at extreme temperatures of up to 1000°C.

References

[1] M.A. Sutton, W.J. Wolters, W.H. Peters, W.F. Ranson and S.R. McNeill: *Determination of Displacements using an Improved Digital Correlation Method*. Image Vision Comput, Vol. 1 (1983), p. 133–139.

[2] X. Chen, N. Nu, L. Yang and D. Xiang: *High temperature displacement and strain measurement using a monochromatic light illuminated stereo digital image correlation system*, Meas. Sci. Technol., Vol. 23 (2012), p. 1-9.

[3] B.M.B. Grant, H.J. Stone, P.J. Withers and M. Preuss: *High-temperature strain field measurement using digital image correlation,* J. Strain Analysis, Vol. 44 (2009), p. 263-271.

[4] B. Pan, D. Wu and L. Yu: *Optimization of a three-dimensional digital image correlation system for deformation in extreme environments,* Applied Optics, Vol. 51 (2012), p. 4409-4419.

[5] Y. Sakanashi, S. Gungor and J. Bouchard: *Measurement of local creep properties in stainless steel welds, 4th International Conference on Integrity of High Temperature Welds*, 25-27 September 2012, London.