Evaluation of the reliability of 2D and 3D DIC creep deformation measurements

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Abstract. Characterisation of deformation at high temperature is a critical factor to understand the creep behaviour of safety critical components operating at elevated temperatures. Digital image correlation (DIC) is increasingly becoming popular in characterisation of creep deformation despite a few factors that affects DIC measurements at high temperature. The objective of this paper is to evaluate the reliability of the creep deformation measurements carried out using 2D and 3D DIC. To achieve this, the reference creep test programme was carried using DIC creep test specimens extracted from Nimonic75 bars with certified creep data. The measured DIC and LVDT creep strain data were compared to the certified creep data supplied by the manufacturers of the Nimonic75 bars. The results show that the 2D DIC data fall within the tolerance range of the certified data compared to the 3D DIC test setup. This indicates that with a well-calibrated test machine, a calibrated DIC setup (which is easily achieved in 2D DIC) and good temperature control, the DIC measured creep strains were in good agreement with the certified data set. As for the 3D DIC, more work needs to be done to improve its capability to measure creep strain.

Introduction

Over the past few years, digital image correlation (DIC) has increasingly become popular as a measurement technique to characterise high temperature deformation of engineering materials [1]. Sakanashi *et al* [2] applied DIC to obtain spatially resolved creep strains from a multi-pass weld. With DIC, a single hourglass-shaped specimen has been used not only to characterise the creep deformation but also to study nucleation and cavity growth in high temperature materials[3-5]. Despite these advances in the application of DIC to characterise high temperature deformation, the capability of DIC to reliably characterise creep deformation has not been extensively studied. The objective of this paper is to evaluate the reliability of the creep deformation measurements carried out using 2D and 3D DIC. Evaluating the capability of DIC to reliably characterise high temperature deformation will not only improve the confidence in the application of DIC measured creep deformation for component life assessment but also in highlighting areas which needs to be improved. To evaluate the reliability of the DIC creep deformation measurements, a creep reference test programme based on a certified Nimonic75 test material (CRM425 [6] and ISO204:2018 [7]) was carried out to benchmark the DIC creep testing capabilities.

Experimental setup

2D and 3D DIC test set-ups were used to measure creep strain together with conventional LVDT extensometers. Flat specimens with rectangular cross-section area were used for both 2D and 3D DIC creep tests and a round cross-section specimen was used for 3D DIC creep measurements as well. The test specimens were extracted from Nimonic75 bars with certified creep test data supplied by the manufacturer. The creep testing procedure generally followed that described in ISO204 [7] and the OU DIC monitored creep testing approach set out in [2]. The creep tests were carried out at 600^{o}C with an applied stress of 160MPa.

The DIC system consists of one (2D) or two (3D) Nikon D810 DSLR cameras with 200 mm fixed focal length lens (Nikkor 200 mm micro f4 IF-ED) and Novoflex Ballpro macro bellows. The Nikon camera has a resolution of 7360 × 4912 pixels and 14-bit dynamic range. A random speckle pattern was applied to the specimen surface using a silica ceramic-based matt black and white high temperature resistant spray paint [2]. Images were correlated to calculate the displacements using a commercial program DaVis 8.4 developed by LaVision. A subset size of 101 pixels and a step size of 25 pixels, giving a spatial resolution of 0.1mm was used for both 2D and 3D DIC. The subset size used was adequate for the tests since the gauge section was uniform and the test material is homogeneous hence no change in strain gradients is expected.

Results and Discussion

The LVDT measured the average creep strain of the material spanning the full gauge length. 2D DIC was able to measure the full-field variation in creep strain within the field of view which covered almost the full length of the gauge section, whereas 3D DIC field of view represents less than one-half of the full gauge length. Note that a like for like comparison between the DIC and the LVDT measured creep strain cannot be fully attained as part of the LVDT fixtures covers parts of the specimen gauge section. Table 1 shows the results from the preliminary 2D DIC and 3D DIC reference material creep tests. Figure 1 compares both the LVDT and the DIC measured creep curves with the creep test tolerance range for the certified Nimonic75 material (that is the upper and lower bound tolerance curves computed from $\dot{\varepsilon}_{400} = A\,\sigma^{n}\,exp\left({}^{Q_{400}}/_{RT}\right)$

where $n = 6$ is the stress index and the creep activation energy $Q = 345$ kJ mol^{-1}, the total uncertainty range (21%) including the uncertainty of testing was calculated by the root sum square approach [6]).

The creep strain curves measured by 2D DIC and LVDT follow the same trajectory and fell within the certified uncertainty range. Whereas there is a minor discrepancy between the 3D DIC and the LVDT measured creep strains and both curves fell above the uncertainty range. The higher strain rates in the 3D DIC and LVDT measured creep strains could be attributed to the higher strain variation between the mid-gauge and the end of the gauge section of the test specimens which were observed on the DIC strain maps. These variations could be due to higher temperature on the upper end of the gauge section or perhaps local strain localisation due to change in local materials properties. Further 2D DIC creep tests shows that with a well-calibrated test machine, a calibrated DIC setup and a good temperature control, the DIC measured creep strains can be in good agreement with the certified test data set as can be seen in Figure 1 (2D DIC test3). As for the 3D DIC, more work needs to be done to improve its capability to measure creep strain. From the reference creep tests programme, reliable creep deformation measurements can be obtained from 2D DIC creep tests. For 3D DIC creep measurements, more work is being carried out to address the deficiencies in the test set up.

Table 1 Results from the 2D and 3D DIC creep tests

Parameter	Certified value	3D DIC LVDT/DIC Avg.	2D DIC LVDT/DIC Avg.	Total uncertainty range (21%)	
				Value	Range
Creep rate at 400h ($10^{-6}h^{-1}$)	72	91.6/97.9	85.2/83.8	± 15.3	56.7 ~ 87.3
Time to 2% strain (h)	278	224.0/213.7	247.5/237.3	± 58.4	219.6 ~ 336.4
Time to 4% strain (h)	557	442.1/420.1	481.5/471.8	± 116.4	440.6 ~ 673.4

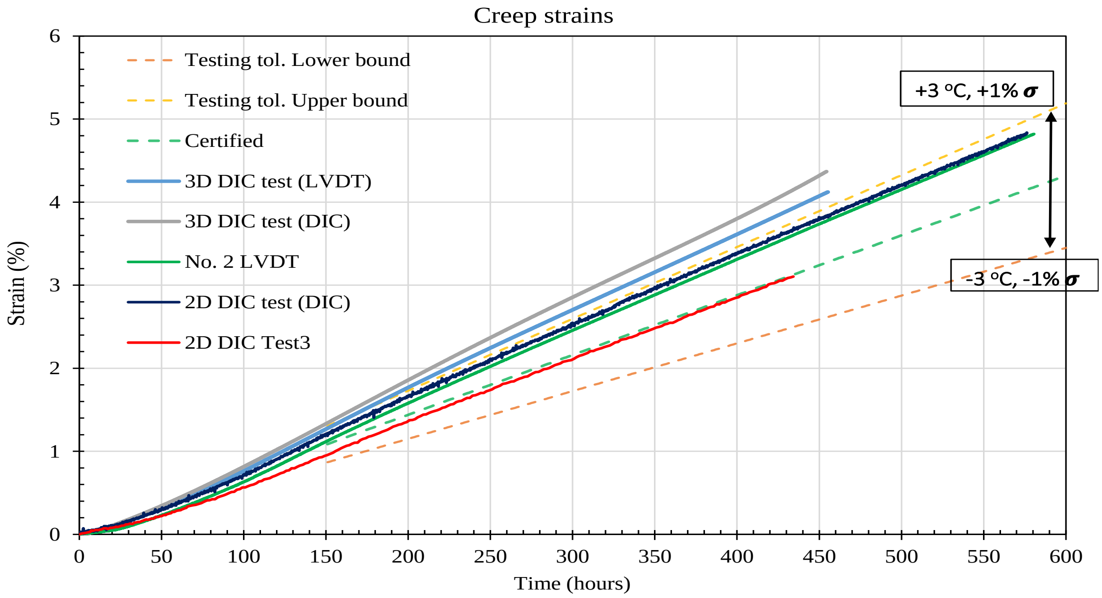

Figure 1 Comparison between DIC and LVDT creep strain measurements to the certified creep data for Nimonic75.

Reference

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