Determination of creep properties from a single specimen using DIC

E. Muyupa, S. Gungor, A. N. Forsey and P. J. Bouchard
Materials Engineering, School of Engineering and Innovation, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK

Abstract

Transient and steady-state creep properties are required for design and remaining life assessments of safety critical components. This is of particular importance for those operating under load at high temperature, such conditions as those found in commercial power generation plants. Standard practice dictates that multiple uniaxial creep tests are carried out to characterise the properties of these materials across a range of applied stress levels and temperatures. For instance, the entire creep tests programme required to satisfy the ASME design code for characterising new high temperature materials would include at least 3 casts with a minimum of 2 tests for a given temperature [1]. The testing must include at least 4 different stress levels at any given temperature and then at 50°C intervals within the operating temperature window. Test durations of more than 30,000 hours per sample are required for a material with design life of 100,000 hours. A similar test requirement is prescribed by the European code of practice for creep strength and rupture assessment [2]. These creep testing programmes required by design codes inflate the cost of developing new high temperature materials. Difficulties in component life assessment can also be encountered due to lack of availability of test material, this can be caused by limited or no availability of archive material. In these cases, a solution is to extract very small samples of material from in service power plant components. This has led to the use of conventional design sub-size (miniature) specimens and the development of non-conventional creep testing techniques such as impression creep and small punch creep testing [3, 4].

In the current work, an investigation has been carried out to assess the feasibility of extracting multiple creep deformation curves, at varying stress levels, from a single specimen with varying cross sectional area, using digital image correlation (DIC). Using a single specimen reduces the aggregated testing time several-fold and therefore is very cost-effective. This testing approach replaces the need for testing at (a minimum of 4) multiple stress levels, with a continuously varying effective stress level along the sample, increasing the effectiveness of the material used. Moreover, extracting multiple creep curves from adjacent locations in the same specimen has the advantage of minimising microstructural variations, which may be an issue for forged components or when multiple specimens are removed from different regions of a large cast.

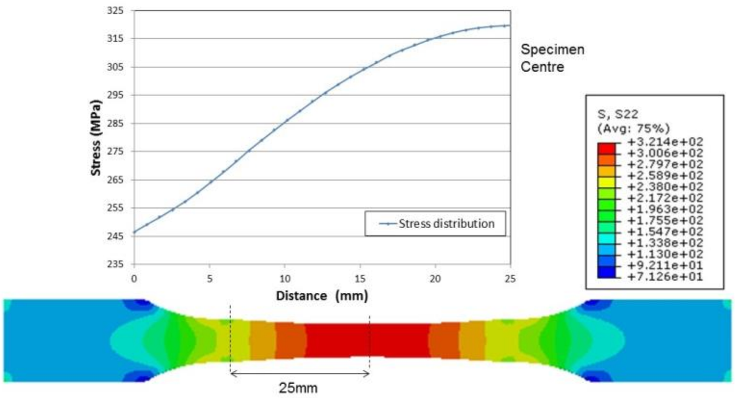
A waisted sample design was designed so that the stress concentration effect of the curvature at the gauge section was minimal, based on finite element modelling (Fig.1), and so that the variation in stress along the sample obeys a known function, to aid post processing. Specimens were machined from a Type 316H stainless steel material using EDM. The specimen thickness was 3 mm and the width at the centre (narrowest point) was 6 mm. High temperature paints were used to spray a black and white speckle pattern onto one face of the specimen for DIC measurements. Creep tests were carried out at 525°C, in a furnace fitted with a bespoke optical sapphire window, to allow imaging of the painted surface during testing. A Nikon D800E colour DSLR camera, with an image resolution of 7360x4912 pixels, was used for image acquisition (Fig. 2). A constant load was applied to give a nominal stress of 320 MPa.

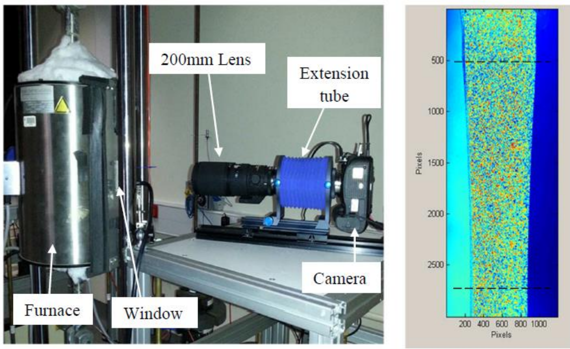
Fig. 3 shows a plot of the variation of longitudinal creep strain at multiple stress levels, extracted from a single waisted specimen, as a function of time. The nominal stress distribution ranges from 250 MPa to 320 MPa continuously, so the material at the centre of the gauge length experiences higher applied stress compared to material at the far end of the gauge length. The difference in creep strain rates in the secondary creep regime, between the low stress and the high stress region, is in the order of five. The results of the waisted specimen tests have been validated by performing several tests with conventional (i.e. constant stress) tests and the primary and secondary creep behaviour have been successfully correlated with RCC-MR creep model.

References:

1. ASME, *Boiler and Pressure Vessel Code - Section II, Part D - Materials Properties*. 2010.
2. ECCC-Recommendations, *High temperature component analysis overview of assessment and design procedures - Volume 9, Part II [Issue 1]*. 2005.
3. Hyde, T. and W. Sun, *A novel, high-sensitivity, small specimen creep test.* The Journal of Strain Analysis for Engineering Design, 2009. **44**(3): p. 171-185.
4. Kumar, J.G. and K. Laha, *Small Punch Creep deformation and rupture behavior of 316L (N) stainless steel.* Materials Science and Engineering: A, 2015. **641**: p. 315-322.

Figure 1. Stress distribution in the waisted specimen design.





(a) (b)

Figure 2. (a) Experimental set-up for DIC monitored creep test of the waisted specimen (b) the specimen as viewed through the furnace window.

Figure 3. Longitudinal creep strain accumulation as a function of time at varying nominal stress.