An inert gas based technique for long-term creep strain measurement by digital image correlation

Zhenxing Hu[1], Jianxin Gao[1*]

[1]TWI Ltd, Granta Park, Great Abington, Cambridge, CB21 6AL, UK

[*]Corresponding author: jianxin.gao@twi.co.uk

Abstract: The measurement of long term deformation, or creep, in industry is of crucial importance to the safe operation of plant and equipment. However, many issues will encounter if digital image correlation was used for strain measurement over a long term on a component without special treatments outside of a laboratory. Such issues include noise due to the harsh environment, fixture of the imaging system, degeneration of the speckle patterns, and oxidation at high temperature. To address these issues, we propose a new technique where inert gas such as argon is used to seal the inspection area of a component and prevent it from oxidation at high temperature. The sealing is achieved by a mechanical fastening device rather than by welding, so that no further damage to the parent material of the component under investigation will occur. This mechanical sealing is expected to last over prolonged period of time, so that in situ long-term creep strain can be measured. Preliminary laboratory test up to two weeks had proved the effectiveness of the technique. Further validation tests over six months even several years are ongoing.

Keywords: Creep measurement, high-temperature, digital image correlation

1. Introduction

Creep deformation eventually leads to failure of components where the component has been exposed to high levels of stress which are below the yield strength of the materials. Materials that are subject to heat for long periods are more prone to creep as creep increases as a function of temperature. Thus measuring creep in high temperature environments, such as power plants, is essential to prevent their failure which can have catastrophic consequences. In high temperature environments, replica metallography is one of the most commonly used methods for creep damage detection. Other techniques which can be potentially used for creep monitoring include strain gauges, electrical potential drop techniques, positron annihilation, X-ray diffraction and small angle neutron scattering, hardness measurement, ultrasonic and magnetic methods. However these are either unreliable or difficult to apply in high temperature environments.

Digital Image Correlation (DIC) is an optical technique for mapping the two-dimensional strain field over an area rather than the average strain between two fixed points [1]. Hence accurate strain measurements can be obtained. It has great potential for creep measurement at elevated temperature.

In practice, one approach when using DIC is the use of a coating over the inspection area on a foil to enable better visual images to be acquired [2]. The main drawback of the technique is the ability of the coating to withstand and survive temperature cycling due to thermal mismatch between the coating and foil. Another critical drawback is that the deformation of the foil may not reflect the actual deformation of the parent material underneath, as the foil can only be welded to the parent material along the boundaries. Hulstof et al. [3] alternatively proposed a technique which uses a thin inert metal such as gold to be placed on the material to be measured and covered by a device that is permanently mounted on the material. The deformation of this inert metal part is measured representing the creep deformation that the material is experiencing. As with other similar techniques, drawbacks include the secure attachment of the metal to the underlying material thus affecting deformation and hence measurements. Again the deformation of the inert metal may not reflect the actual deformation of the parent material underneath, as the inert metal can only be welded to the parent material in limited areas e.g. along the boundaries.

2. Inert gas based technique

Since the key issue in long-term creep strain measurement at high temperature is oxidation, we propose a technique using insert gas to address it directly. With this technique, the air surrounding the inspected area is expelled by a sealing device for the whole duration of the successive measurements.

Alternatively a vacuum could be used but is difficult to achieve, so inert gas replacement is optimal. One possible sealing mechanism is illustrated in Figure 1.

To ensure that the mechanical sealing works over a prolonged period of time, a curved sliver ring (as opposed to commonly used copper O-ring) has been designed. Such a silver seal will not only resist oxidation at high temperature up to 650°C, but also can survive the numerous temperature cycles between ambient and operating temperatures.

Using the above technique, coating of the inspection area is not required. The changes in micro-indentation of the component surface are utilised for creep measurement via DIC. Thus issues concerning adherence of the coating on the surface (inspection area) and degradation of the coating and oxidation at high temperature are overcome.

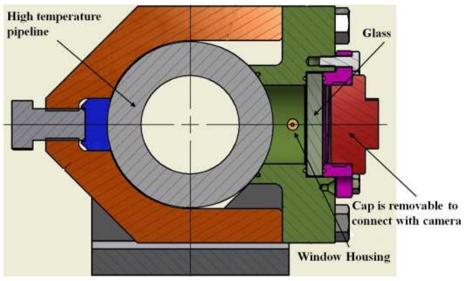

Figure 1. Section of the apparatus for creep strain measurement using inert gas and silver O'ring sealing

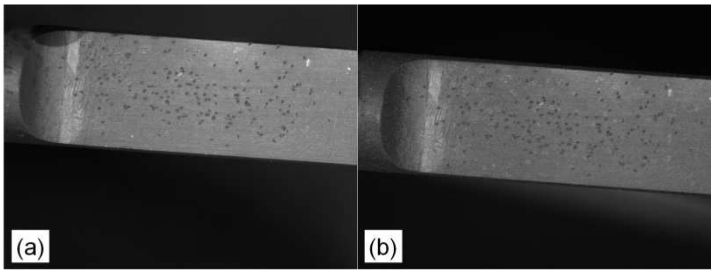

Figure 2. Frontal Images of 7-days (a) and 14-days (b) in heating at 600^{O}C

The protective enclosure will be mounted to the component surface. An optically transparent window will be installed so that digital images can be acquired in follow-up inspection without opening the sealing enclosure. Obviously, the glass window shall be strong enough to withstand the internal pressure which will be built up at high temperature. A theoretical analysis showed that the internal pressure would approximately reach 3 times atmospheric pressure (atm) when an air-tight protective enclosure is heated up to 600 ºC from room temperature. The inert gas may be any suitable gas that would diminish or eliminate the deterioration, specifically oxidation, of the inspection surface. Argon is preferred in our test.

3. Tests

As a first step to validate the proposed technique, a preliminary test was performed where a steel cylindrical chamber was used as the enclosure. A P91 sample with micro indentations as the speckle pattern using a 0.6mm drill was placed inside the cylindrical chamber. The sample was maintained in an argon atmosphere during further heating, so that the internal pressure (3 atm) which would be built up when the chamber was heated to 600 ºC can be withstood. The chamber was heated for 7 days at 600ºC. An image of the sample was then acquired as shown in Figure 2(a). The dents can be clearly observed, with the only change to the overall appearance being a change in colour from the initial silver colour to grey. The sample was then heated for a further 7 days at 600ºC where a new image was acquired as shown in Figure 2(b). It can again be seen that the dents are clearly visible. Oxidation of the sample is not evident although glittery dots were observed, which was the remnant of lubrication oil that the sample was exposed to after the first elevated temperature trial. Nevertheless, the strain between these two images calculated using DIC algorithm showed a value of $2.2\text{x}10^{-4}$ compared with the actual zero creep strain, indicating high measurement accuracy.

Further tests over many months and even years using the proposed technique have been planned, where a mechanically sealed enclosure is under fabrication. Afterward, in-situ creep strain measurement in a practical power plant over prolonged period of time will be carried out in the near future.

References

1. W. H. Peters and W. F. Ranson, Digital Imaging Techniques In Experimental Stress Analysis, Opt. Eng. 21(3), 1982
2. H.J.M. Hulshof, P. G.M. Welberg, Creep strain measurements for risk based monitoring of steam pipes and headers, ECCC Creep Conference, Sept. 2005, London.
3. H. Hulshof, M. Jozef, Method and apparatus for measuring of displacements within a plane, Patent: WO2000042382 A1, 2000