Comparison of DIC Measurements and FEM Predictions for Thermally Induced Deformation of a Stainless Steel Tube

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Abstract
Experimental analysis of the thermo-mechanical response of stainless steel was performed using digital image correlation technique and high-fidelity full-field deformation data was acquired for quantitative comparison with predictions from a finite element (FE) model to illustrate the use of a probabilistic validity statement. Future work will investigate the acquisition of deformation data using the DIC method for combined thermal-pressure loading and the subsequent quantitative comparison with predictions from a coupled thermal-pressure FE model to develop a validation approach that can be applied to multi-physics problems.

Keywords: digital image correlation, validation, multi-physics, image decomposition, probability bound analysis, relative error, model uncertainty.

Introduction

Analysis of thermal stresses and strains due to non-uniform temperature distributions is important for assessing structural integrity of engineering designs. Until recently, engineers have only used point-by-point measurements from strain gauges in structural analysis and validation assessment. However, this does not allow the global strain distribution to be measured and may lead to significant areas of the test component where there is no empirical information resulting in a partial validation [1]. Since, it is good practise to use comparable data from both experiment and simulation for a validation assessment [2], this issue can be alleviated by using a modern full-field measurement technology, such as digital image correlation (DIC). DIC is a full-field, non-contact optical technique that uses multiple cameras to capture stereoscopic images of the component under test at time intervals during loading, and produces data-rich maps of displacements or strain over a region of interest (ROI). It has recently been applied to high temperature components [3] and it is viable for a quantitative validation assessment.

DIC technique will be used for this research to acquire spatial images of thermal strain data for a tube subject to internal heating. The images acquired with DIC contain 10^6 data points; and, hence a data reduction technique based on image decomposition will be used to decompose the strain images to vectors containing less than 10^2 elements, whilst retaining all of the useful data present in the image. This is perform to allow a quantitative comparison with the predictions from an FE model using a validation metric based on absolute relative error.

Research Method

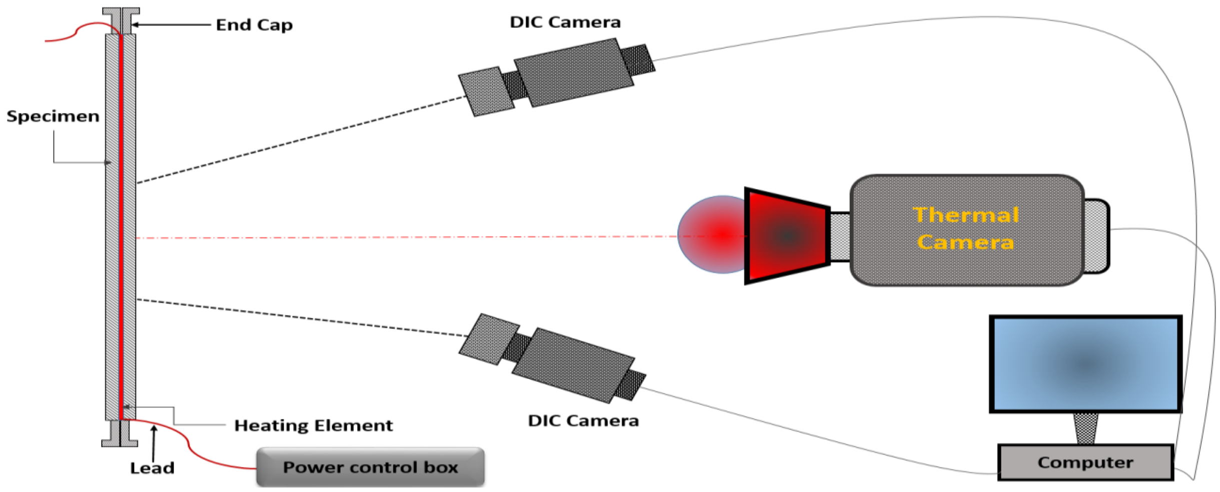

Figure 1 DIC experimental setup for full-field thermal analysis

Experiment Design: The test component is made of AISI grade 316l cylindrical stainless steel (modulus of elasticity = 193 MPa). The diameter, length, and thickness of the cylindrical tube are approximately 20mm, 300 mm, and 1 mm respectively and the outside surface is painted with a speckle pattern using high temperature paint. The component is subjected to internal heating from room temperature to 600 ^{0}C, using an infrared heating element. The response quantity of interest in this work is the mean maximum principal strains obtained as a function of temperatures and time. Figure 1 indicates the experimental setup.

The component is fitted with specially designed end caps made from mild steel to hold the heating element in central on the axis of the tube, and the tube is supported in the horizontal plane by a clamp supporting system. A reference image of the undeformed specimen is captured at room temperature and at 25 ^{0}C increments up to a temperature of 600 ^{0}C. A thermal imaging system is integrated into the experimental setup to provide temperature distribution data that can be used as input file for the thermo-mechanical finite element analysis and for the validation assessment.

Computational Model: ABAQUS finite element code has been used to construct a three-dimensional model of the cylinder in order to conduct a thermo-mechanical simulation. The model is made of three dimensional hexahedral, 8-node thermally coupled bricks and temperature elements (C3D8T). The initial temperature was set at 23 ^{0}C and linearly increased to a final temperature of 600 ^{0}C in increments of 25 ^{0}C. Figure 2 shows preliminary results for the maximum principal stresses and nodal temperature distribution.

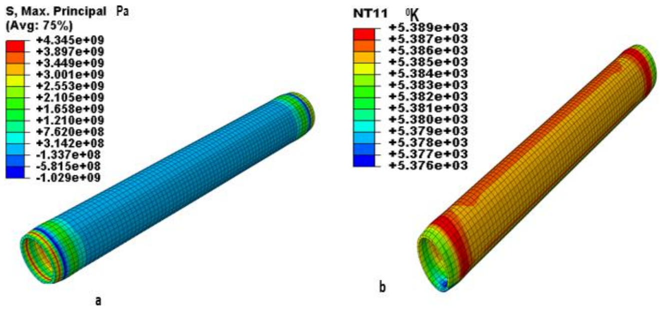

Figure 2 (a) Max principal stress (MPa), (b) Nodal temperature (K)

Data Analysis and Quantitative Comparison

The strain images obtained from both the simulation and experiment are post-processed using image decomposition to allow quantitative comparison. Chebyshev polynomials are used to decompose the strain images from both the simulation and the experiment to a pair of feature vectors. The decomposed experimental data is plotted against the simulation data and the allowable scatter is determined by the minimum measurement uncertainty, following the CEN guideline. In addition, probability bound analysis and a validation metric based on absolute relative error is used to quantify the predictive capability of the model for the specific conditions.

Conclusion

An experimental design for a combined thermal-pressure loading condition is described to provide measurement data that can be used to develop a multiphysics validation strategy. A single thermal experiment based on DIC technique has been designed as a step towards realising a multi-physics experiment. The data acquired from the experiment, and simulation will be presented together with a quantitative comparison using a validation metric based on absolute relative error.

Literature References

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