Assessment of Extremely Low Cycle Fatigue behaviour of high strength steel using 3D DIC measurements

D.T. Asquith[1a], V.P. Pasialis[2]

[1]Sheffield Hallam University, Howard Street, S11WB, Sheffield, UK [2]Sheffield Forgemasters, Brightside Ln, S92RW, Sheffield, UK

[a]d.asquith@shu.ac.uk

Abstract. The scope of this study is to investigate the cyclic material behaviour of high-strength nuclear steel SA-508-4N by taking into advantage the advanced measuring capabilities of Digital Image Correlation (DIC). Round dog-bone specimens were tested under fully-reversed Extremely Low Cycle Fatigue (ELCF) with various applied strain amplitudes. By employing DIC to measure extension and necking it was possible to calculate true stress values and therefore assess the true mechanical behaviour of the material under cyclic loading. Depending on the strain amplitude used, steel SA-508-4N was found to exhibit cyclic hardening or perfect plasticity in tension and a rather mixed cyclic softening/hardening behaviour in compression.

Introduction

The aim of this study is to investigate the cyclic material behaviour of high-strength nuclear steel SA-508-4N by taking into advantage the advanced measuring capabilities of Digital Image Correlation (DIC). The use of DIC enables the calculation of true stresses apart from nominal ones. This is achieved by carefully considering a virtual extensometer placed appropriately exactly where the maximum strains occur (Fig. 1). Depending on the geometry of the specimen, the location of the maximum occurring strains is not always known a-priori, which is always the case with uniform-shaped specimens. Even in hourglass-like specimen the location of the critical diameter has to be found after the test for better accuracy, which is the basic advantage of using image capturing techniques like DIC comparing to traditional measuring techniques.

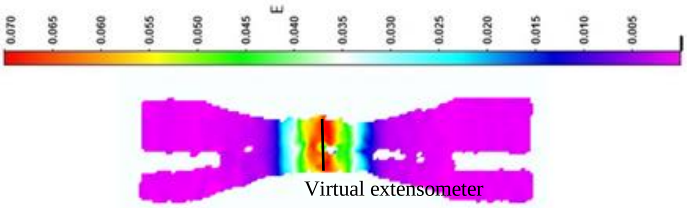

Fig. 1: Horizontal strain field during max tension with strain amplitude equal to ±1.5%.

Experimental procedure

The experimental equipment comprised an ESH testing machine capable to deliver up to 250kN tensile force and a DIC optical system provided by LaVision. The testing machine was calibrated according to BS EN ISO 7500-1:2004 standard [1], while the optical system was calibrated according to CEN/CWA 16799 standard [2]. A number of six round dog-bone specimens were prepared according to ASTM E606/E606M-12 [3] and tested under fully-reversed ELCF. The selected type of specimen is less prone to buckle during fully reversed cycling, according to the relative reference [4].The applied strain amplitudes were ±2%, ±1.5% and ±1%. The recording rate of the optical system was 4fr/s while the cycle rate was 0.05Hz, which resulted in the acquisition of a number of 80 images per cycle. Prior to testing a speckle pattern was sprayed on the visible surface of the specimens.

Results

Presented in Fig. 2 are the maximum nominal and true stresses occurring at ±2% strain amplitude versus the cycles of loading. It is obvious that depending on the definition of stress, largely different results may be obtained. Results also depend on the selection of the gauge length. In Fig. 3 the dependency of the plastic strain amplitude $\Delta\varepsilon_p$ versus the loading cycles at strain amplitude equal to ±2% is displayed. It is evident that plasticity is a highly localized event which tends to become more intense with loading cycles.

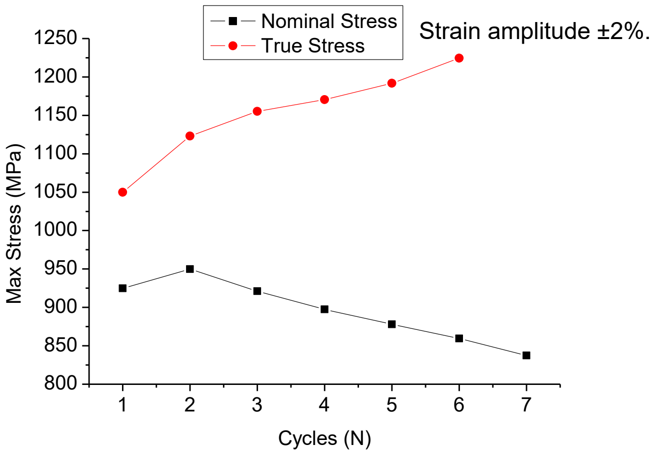

Fig. 2: Variation of maximum stresses at tension with number of cycles, for strain amplitude equal to ±2%.

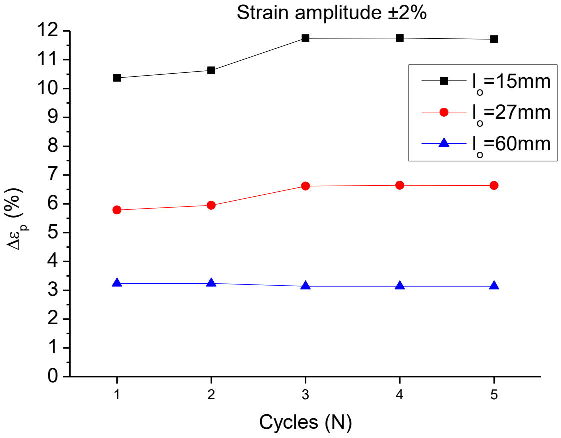

Fig. 3: $\Delta\varepsilon_p$ versus cycles at strain amplitude of ±2%, for different gauge lengths.

Conclusion

The integration of fatigue testing with an advanced measuring technique, like DIC, offered some important advantages compared to traditional measuring techniques. It was found that the loading bearing capacity of the samples tested was being reduced during service life while the material itself exhibited very good hardening capabilities in certain occasions. By using DIC it is easier to decide on the appropriate location to measure the cross-sectional reduction after the test and not before, since generally the position of the final necking is not known a-priori.

Acknowledgement

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References

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