Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 160 (2016) 285 – 291

Procedia Engineering

www.elsevier.com/locate/procedia

XVIII International Colloquium on Mechanical Fatigue of Metals (ICMFM XVIII)

A novel method for uniaxial HCF testing of austenitic stainless steels

S. Cruchley[a], M. Twite[a]*, A. Tweddle[b], G. Wagner[c], A. Wisbey[c], R. Lee[c]

[a]*Rolls-Royce plc, PO Box 2000, Derby, DE21 7XX, UK*
[b]*Formerly at Rolls-Royce plc, PO Box 2000, Derby, DE21 7XX, UK*
[c]*Amec Foster Wheeler, Walton House, Faraday Street, Birchwood, Risley, WA3 6GA, UK*

Abstract

Fatigue endurance testing of nuclear plant materials is typically carried out using uniaxial specimens tested under strain control using a triangular waveform and a defined strain rate. This leads to long test durations and high testing costs when testing in the High Cycle Fatigue (HCF) regime, meaning few results for fatigue lives above 10^6 cycles are available. A novel test method is proposed here, in which the traditional strain-controlled test method is used until 10^5 cycles have elapsed, before testing is switched to load control at a higher frequency. Testing of a Type 304LN austenitic stainless steel in room temperature air was performed at an R ratio of -1, strain rate of 0.4%/s and strain amplitude of 0.18%. The results show no statistically significant difference between the HCF lives gained from the traditional and new test methods. The proposed new fatigue endurance test method is considered to be validated for use in the testing of nuclear grades of unstabilised austenitic stainless steel in air at room temperature.

Peer-review under responsibility of the University of Oviedo

Keywords: High Cycle Fatigue; Testing; Strain control; Load control; Stainless Steel; Nuclear

1. Introduction

In nuclear plant applications, High Cycle Fatigue (HCF) is taken to mean cyclic loading conditions under which

* Corresponding author. Tel.: +44 (0)1332 637842.
E-mail address: marius.twite@rolls-royce.com

Peer-review under responsibility of the University of Oviedo
doi:10.1016/j.proeng.2016.08.892

fatigue lives are greater than around 10^4 cycles. Fatigue endurance testing of nuclear plant materials is typically carried out under strain control using a triangular waveform and a defined strain rate instead of a defined cyclic frequency.

This approach to fatigue means that, when testing under HCF conditions, test durations are long and therefore testing is expensive. Consequently, relatively few HCF test results, particularly for lives of 10^6 cycles and above, are available for inclusion in databases. For example, the database of austenitic stainless steel test results compiled by Argonne National Laboratory (ANL) and analysed in NUREG/CR-6909 [1], and which was used as the basis for update to the design fatigue curve in Section III of the ASME Boiler and Pressure Vessel Code [2], contains far fewer results for HCF conditions that for Low Cycle Fatigue (LCF) conditions, and a large proportion of the HCF results for lives greater than 10^6 cycles are run-outs (test is considered finished prior to specimen failure). For nuclear plant materials, a single data fit is typically produced for all test results throughout the range of strain amplitudes relevant to plant operation, and the overall shape of a best-fit curve may be highly sensitive to results at the extremes of this range, including HCF results.

In an attempt to address these difficulties, a test programme has been undertaken to investigate the use of an alternative test method in which traditional strain-controlled testing (with a constant strain rate) is used until 10^5 cycles have elapsed, and then testing is switched to load control at a higher frequency. The load amplitude is matched to that recorded during the final cycles under the strain-controlled portion of the test. Cycling under load control is continued until specimen failure. This method of testing for long-life conditions (HCF) is permitted within the ASTM E606 standard for strain-controlled fatigue testing [3].

Similar fatigue endurance test methods are known to have been used in the past for aerospace and automotive materials [e.g. 4, 5], but no direct comparisons of the results from testing under strain control (throughout a test) and with a switch from strain control to load control have been found in the literature. The use of this testing approach for nuclear plant materials is considered to be novel.

2. Experimental method

Testing was carried out in room temperature air (22ºC ± 2ºC) at constant humidity (50% ± 10%) using a single cast of Type 304LN austenitic stainless steel which was forged to produce a pressure vessel nozzle and then solution heat treated. The alloy composition is given in Table 1 and the alloy is estimated to contain around 2% delta ferrite based on this composition. Uniaxial fatigue endurance testing was completed at a constant strain amplitude of 0.18%, an R ratio of -1 (with respect to strain) and a triangular waveform. The strain amplitude of 0.18% was chosen based on the results of previous tests which indicated this amplitude was towards the fatigue limit (well into the HCF regime) and was expected to give lives in the range 5×10^5 to 10^6 cycles. Thirteen uniaxial fatigue specimens (Fig. 1) with an arithmetic average surface roughness (R_a) of less than 0.2 µm were tested. Testing was performed using one of the following four different methods, at Amec Foster Wheeler's Birchwood Park (UK) laboratories on behalf of Rolls-Royce.

- Strain-controlled fatigue testing on a servo-electric test machine at a strain rate of 0.4%/s and strain amplitude of 0.18%, which equates to a frequency of 0.556 Hz. This was the extant test method used in previous testing of the same cast of material.
- Strain-controlled fatigue testing on a servo-hydraulic test machine at a strain rate of 0.4%/s and strain amplitude of 0.18%, which equates to a frequency of 0.556 Hz.
- Strain-controlled fatigue testing on a servo-hydraulic test machine at a strain rate of 0.4%/s and strain amplitude of 0.18%, which equates to a frequency of 0.556 Hz, switching to load control at 5 Hz once 10^5 cycles had been reached.
- Strain-controlled fatigue testing on a servo-hydraulic test machine at a strain rate of 0.4%/s and strain amplitude of 0.18%, which equates to a frequency of 0.556 Hz, switching to load control at 10 Hz once 10^5 cycles had been reached.

All testing machines are capable of applying tension-compression fatigue testing with no drive backlash at zero load, and a Class 10 alignment was achieved in all cases using the BS ISO 23788:2012 standard [6]. Class 10 refers