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An effective method to investigate short crack growth behaviour by reverse bending testing

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Abstract

A reverse bending rig has the advantage of relatively cheap construction compared with servo-controlled machines, and its robustness and reliability make it ideally suited to long-term testing programmes. In this paper, the details of the mechanical mechanism of a bending rig, the methods of its strain measurement and stress–strain analysis have been presented. A series of tests has been carried out to investigate short crack growth behaviour of AISI type 316 stainless steel under creep–fatigue conditions at 550 °C. The advantage of this type of test allows a comparison to be made, on one specimen, of the influence of both tensile and compressive hold periods on crack growth behaviour. It has been shown that predominantly intergranular long cracks form on the tensile side and transgranular short cracks on the compressive side and these are a prominent feature between 0.9% and 2.5% strain range.

Keywords: Creep-fatigue; Short crack; Crack coalescence

1. Introduction

Materials subjected to high temperature service are usually exposed to complex strain-time histories and experience differing damage modes. Creep damage, which is a time-dependent process, depends primarily on the history of stress and temperature applied to the component; whereas fatigue damage is generated by the cyclic stress and depends primarily on time-independent plastic strain. The imposition of one form of damage is also known to influence the other. When the two damage components act in a combined manner, a creep–fatigue interaction develops [1–3]. The basic reason for the creep–fatigue effect can best be understood by detailed consideration of the stress–strain pattern involved during cycling with a tensile hold period. During the tensile hold period, stress relaxation occurs at a range of strain rates, similar to those encountered during creep testing, and produces an additional amount of tensile strain to that produced from fatigue cycling. Although this additional strain, which is given by the amount of stress relaxation divided by Young's modulus, is less than 0.1% per cycle, it has a drastic effect on the life [4].

Many service conditions result in creep–fatigue damage. For example, the current high price of fossil fuels and the increased use of large nuclear plant for base-load electric power generation have resulted in increased shift operation of fossil-fired plant. Between start-up and shut-down there is a period of on-load running. The material at the surface of a stress concentrating feature may be at constant strain during this period, and stress relaxation will take place by creep. Similar types of situation arise also in steam turbine components, pressure vessels and gas turbines. To design any of these components for satisfactory operation requires an understanding of the mechanisms which occur in the creep–fatigue processes. In particular, the creep–fatigue endurance of the type 300 series austenitic stainless steels

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has received a great deal of attention because of their various applications in the power generation industry and particularly the nuclear industry.

In 1961, Forrest and Penfold [5] first reported on a reverse bending fatigue machine which they had developed for thermal fatigue testing. A bar specimen of rectangular cross-section was bent through a predetermined angle of deflection, producing alternating strain on the top and bottom surfaces of the specimen. In 1963 Forrest and Armstrong [6] reported on strain controlled fatigue tests performed on Nimonic alloys using a number of these reverse bending machines. A large number of machines were later built within the UK for the testing of power plant materials [7–9]. Subsequently, there have been substantial developments in uniaxial push–pull fatigue testing and most tests are now performed on such machines. Until now, most information from reverse bending tests are related to long crack investigation and there is still limited information available on short crack investigation using reverse bending rigs in the literature, although reverse bending machines are of particular benefit in creep/fatigue tests [10–12]. Fully reversed bending creep–fatigue tests can be performed on a displacement controlled high temperature bending rig. Its relatively cheap construction compared with servo-controlled machines together with its robustness and reliability make it ideally suited to long-term testing programmes. When a hold time is introduced into a bend specimen, one side is subjected to a tensile hold period, while the opposite side experiences a compressive hold period. Thus this type of test allows a comparison to be made, on one specimen, of the influence of both tensile and compressive hold periods on crack growth behaviour [13,14].

This paper first addresses the mechanical mechanism, the methods of strain measurement and the stress–strain analysis of the reverse bending rig. Then, an investigation of short crack growth behaviour in AISI type 316 stainless steel under creep–fatigue conditions is presented, which shows that reverse bending testing is an effective method to study both tensile and compressive effects on this failure phenomenon simultaneously.

2. Reverse bending rig

2.1. Mechanical mechanism of the bending rig

A schematic view of the mechanical mechanism of the bending rig is shown in Fig. 1. A full description of the rig can be found in Ref. [15,16], and only a brief introduction is presented here. The test specimen was clamped by two horizontal cross-shafts made of type 316 stainless steel using removable clamping plates. It was strained in pure bending by rotation of the cross-shafts about their axes. The development of a net tensile stress in the specimen during bending was avoided by allowing one of the cross-shafts to move horizontally in slots as well as to rotate. Both cross-shafts were connected to cross-beams by means of a pair of lever arms. Two loading arms were fixed on the cross-beams at one end of the specimen and connected via bearings eccentrically on two pulleys on the other end. The drive for the rig was provided by a DC motor, having a 2000 rpm maximum speed,

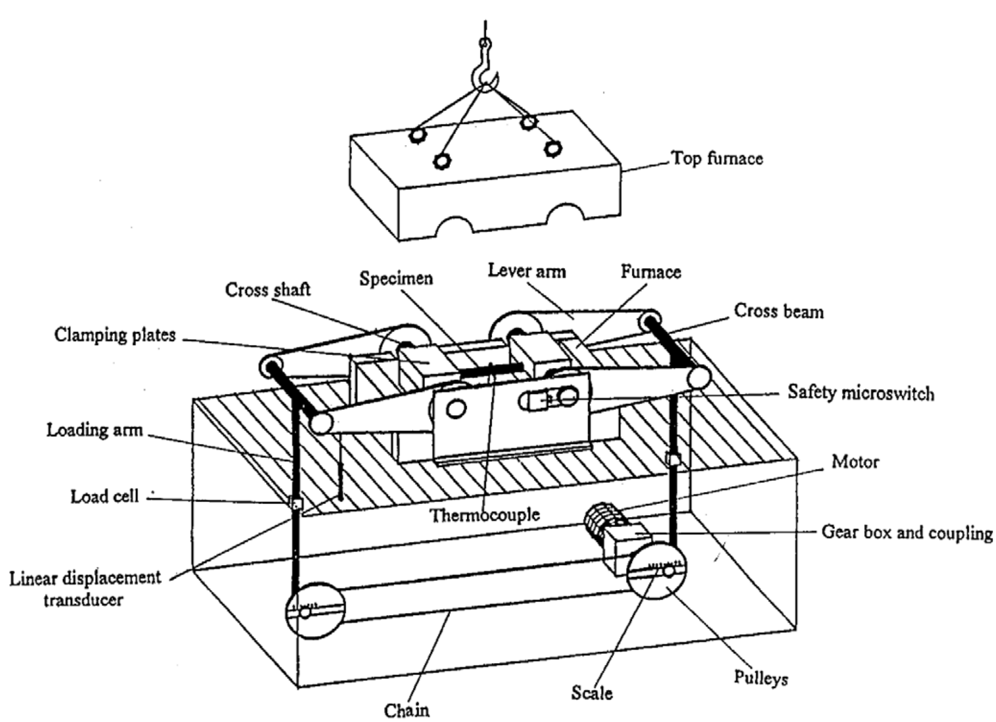

Fig. 1. A schematic view of the mechanical mechanism of the bending rig.