The Effect of Microstructure on the Dissipative Heat Source in 316L Stainless Steel

P.J. Seelan[1a], J.M. Dulieu-Barton[1], F. Pierron[1]

[1] Faculty of Engineering and the Environment, University of Southampton, Highfield, Southampton

SO17 1BJ, United Kingdom

[a]p.jayaseelan@soton.ac.uk

Abstract. When a material is subjected to mechanical loads, the thermodynamically irreversible processes occurring within the microstructure of the material causes an increase in the temperature of the material; this is known as intrinsic dissipation [1]. By using an infrared camera to measure this temperature rise, the dissipation can be obtained and expressed as a heat source using the heat diffusion equation [2]. The present study investigates the effect of different microstructures on the dissipative heat source of 316 L.

Introduction

When a material is subjected to cyclic loads, it experiences a cyclic temperature variation proportional to the applied stress; this is due to the thermoelastic effect [3]. On the other hand dissipation causes a temperature rise. However, the temperature rise itself is not intrinsic to the material behaviour as it is affected by thermal exchanges between the specimen and its environment. Therefore, the heat source must be obtained from the heat diffusion equation [2] as this relates directly to the material behaviour:

$$\rho C\frac{\partial\theta}{\partial t}-\left[\frac{\partial\theta}{\partial t}\right]_{(t=0^-)}-k\Delta\theta+\rho C\frac{\theta}{\tau}=S_D+S_{TE} \tag{1}$$

where S_D is the dissipative source, S_{TE} is the thermoelastic source [3], ρ is the material density, C is the specific heat, *k* is the thermal conductivity, Δ is the Laplacian operator, θ is the local temperature variation of the specimen due to the thermomechanical sources, and τ is a time constant characterizing the convection and radiation losses [4].

When metallic materials are subjected to mechanical deformation a dissipative heat source is generated as a result of the movement of dislocations, among other less important mechanisms. When the cyclic loading regime is below the macroscopic yield stress the dissipative heat source caused by the reversible movement of dislocations is constant but small and measurable [1]. At cyclic loads above the macroscopic yield stress, the irreversible movement of dislocation caused by the creation of new dislocations increases the dissipative heat source significantly. The sensitivity of the dissipative heat source to microstructural evolution was explored by Connesson et al. in [5]. It was found that the dissipative heat source of 316L stainless steel increases with cumulative plastic strain. As such, the present work explores further the effect of microstructural modification on the dissipative heat source at different levels plasticity/hardening by generating a range of microstructures by utilising different heat treatments. The evolution of the dissipative heat source during cyclic hardening of the different microstructures of 316 L will be examined in detail.

Experimental Work

A range of heat treatments was carried out on AISI 316L to produce different microstructures. Strip specimens of dimension 300 mm × 20 mm × 2 mm were uniformly heated at 1150 ˚C (i.e. the annealing temperature of AISI 316L) for an hour and then cooled at different rates in a controlled vacuum furnace. Another set of identical specimens were tested in the as received condition. Micrographs of these heat treated specimens were taken to establish the differences between the microstructure, primarily the grain size. The mechanical properties of the heat treated and as received materials were also established by tensile testing.

The specimens were subjected to uniaxial cyclic load of various stress amplitudes below and just about the yield stress, at a stress ratio, R_σ of 0.1 using an Instron 8800 servo-hydraulic testing machine. The resulting temperature variations were recorded using a Cedip Silver 480M infrared detector. As the temperature variations expected is lower than the thermal resolution of the infrared detector it is important to reduce background radiation which is one of the main sources of noise. The necessary thermal insulation was provided in the form of a chamber (polystyrene covered with Aluminium foil) placed surrounding the specimen (see Fig.1 (a)). The entire path connecting the camera to the opening of the chamber was also protected using the same chamber material. Besides that, a reference specimen [2] made of the same material as the specimen was placed next to the specimen (see Fig. 1 (b)). This ensures that the fluctuations in the environmental temperature can be taken into account. Data processing methods developed by Maquin and Pierron [2] have also been adapted and implemented to overcome the limited detector sensitivity. The data processing procedure will be described in detail. The main aspect of this being spatial averaging where the frames have been averaged to increase the signal to noise ratio. This was possible as the temperature distribution in each frame of the specimen is uniform due to the macroscopically uniform stress field in the strip specimen. The detection threshold of the combined experimental setup and data processing method was assessed by recording and processing data without cyclically loading the specimen. Initial work has shown that the detection threshold is approximately 1mK.s^{-1}. This detection threshold is adequate to measure the dissipative heat source at cyclic loads below the macroscopic yield stress.

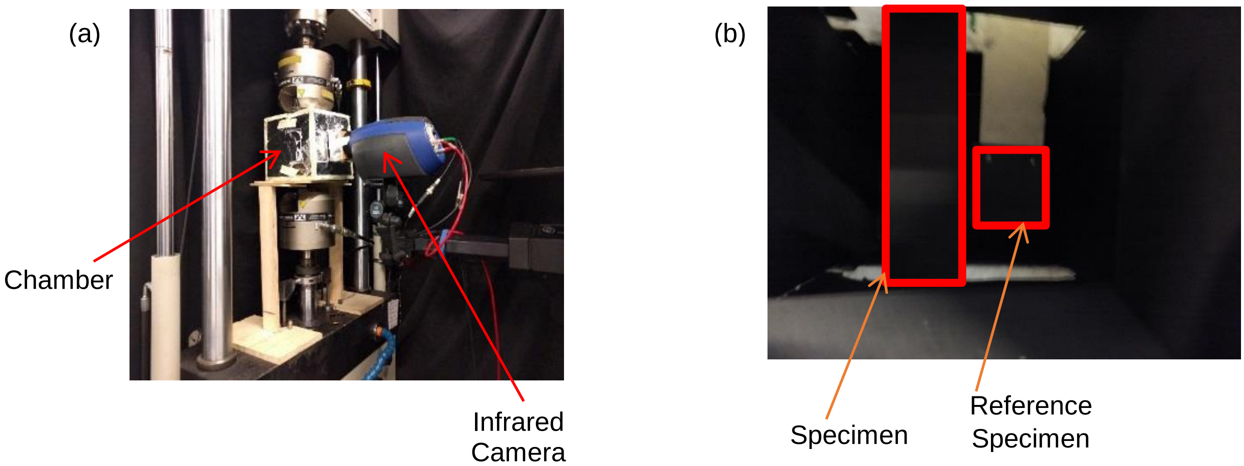

Figure 1(a) Setup of the actual experiment (b) specimen and reference specimen

Conclusion

The microstructures generated through different heat treatments were observed and their mechanical properties were compared. The dissipative heat source of the different 316 L microstructures were examined at cyclic loads below and above the macroscopic yield stress.

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