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Several aspects of the temperature history in relation to the cyclic behaviour of an austenitic stainless steel

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ABSTRACT

A consistent mechanical and transmission electron microscopy (TEM) database is proposed to discuss the consequences of dynamic strain ageing (DSA) on the temperature history memory effect observed under the cyclic loading of a 316LN austenitic stainless steel. Two DSA mechanisms have been identified in relation with two temperature regimes: the first of which may be related to the Suzuki effect (in the low temperature regime) and the second is linked to solute segregation at dislocation node (in the high temperature regime). The temperature history memory effect is a function of the temperature range and can be explained in terms of chromium segregation and the potentiality to obtain “stability” in dipolar dislocation structures. Both aspects are discussed based on the measurement of internal stress changes.

1. Introduction

The cyclic behaviour of austenitic stainless steels for different isothermal conditions has been extensively studied in the past [1–8]. Cyclic hardening, generally observed on stress amplitude *versus* cyclic number curves, depends on the temperature and the strain rate. This should indicate that the physical processes involved during cyclic loadings are thermally activated. While the 316L cyclic hardening curve is quite similar to the curves of pure f.c.c. metals in a large temperature range, non-conventional effects of temperature are reported for 316L grades [1–7,9,10]. Specifically, dynamic strain ageing (DSA) has been reported to occur in a temperature range of 523–973 K under cyclic loadings; DSA shows itself as a serrated flow on stress–strain curves, and it may increase cyclic hardening in specific temperature ranges [9]. The origin of this additional hardening has not been clearly established under cyclic loading. It seems that two temperature regimes exist [9]. The first one (∼523–623 K), where DSA enhances planar slip in relation to carbon segregation on stacking faults, has been reported under cyclic-creep tests [11] and under cyclic plastic controlled tests [1]. The second one (∼773–973 K), where DSA promotes dislocation patterning in relation to chromium segregation on dislocation junctions, has been recently studied [9]. Despite these studies, only one peak stress has been generally reported on the curve describing saturation stress amplitude *versus* temperature. Moreover, from a mechanical point of view, microscopic hardening is represented by different internal stresses; an accurate association between the physical mechanisms and these internal stresses must still be made when DSA occurs. In the visco-plastic regime, mechanical loadings generally lead to a heterogeneous organization of dislocations accompanied by notable hardening. Consequently, it is necessary to accurately characterize the various dislocation structures, as well as the conditions that lead to their formation in order to efficiently describe the mechanical behaviour of metals by means of a physical formalism. A wide experimental database has been partially created in the case of austenitic stainless steels at room temperature. A unified view of the various structures was proposed in the form of Pedersen's map [12,13] and can be used to discuss internal stresses states [13]. However, the impact of temperature on dislocation patterning, and consequently on long-range internal stresses occurring in these dislocation configurations, has not been clearly explored.

Furthermore, a temperature history memory effect has been reported between 550 K and 873 K on austenitic stainless steel

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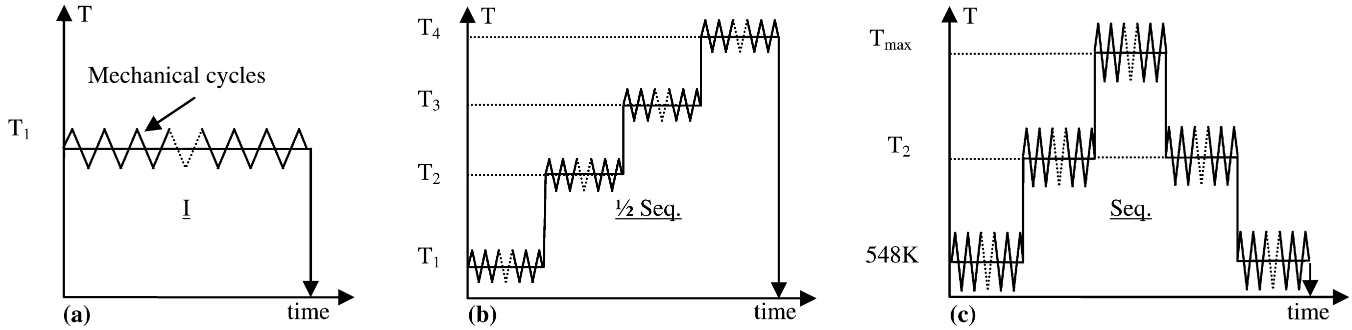

Fig. 1. Three different testing conditions: isothermal (a), successive increasing temperature steps (b) and successive increasing then decreasing temperature steps.

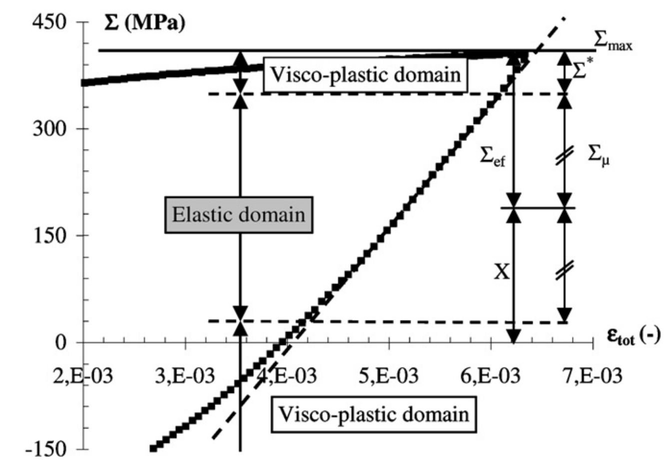

Fig. 2. Stress decomposition in accordance with the Dickson's method on the stress unloading stage.

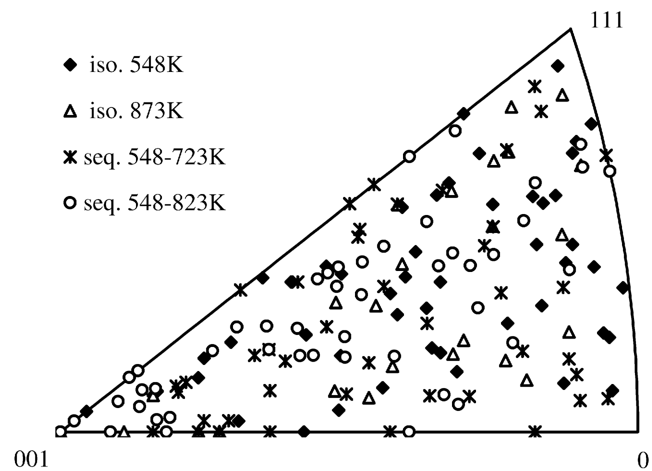

Fig. 3. Inverse pole figure associated with the different cyclic loading studied. The position of one grain is defined by the orientation of the tensile axis on the inverse pole figure. Iso. 548 K and Iso. 873 K correspond to isothermal tests, Seq. 548–723 K and Seq. 548–823 K are anisothermal sequential tests for different temperature steps: 548 K → 623 K → 723 K → 623 K → 548 K and 548 K → 773 K → 823 K → 773 K → 548 K.

in the case of sequential anisothermal cyclic loadings [14,15]. A macroscopic model was proposed by Bouchou and Delobelle [14], but the physical mechanism was not investigated. The purpose of this paper is to establish the correlation between the temperature history memory effect and DSA regimes in order to improve the mechanical models describing anisothermal behaviour under cyclic loading. Section 2 of this paper describes the mechanical tests and the transmission electron microscopy (TEM) method used in this study. Section 3 outlines the main mechanical results and their correlation with dislocation features: isotherm and anisothermal conditions have been distinguished. The last section deals with the main focus of our investigations—an explanation of the temperature history memory effect in terms of DSA processes.

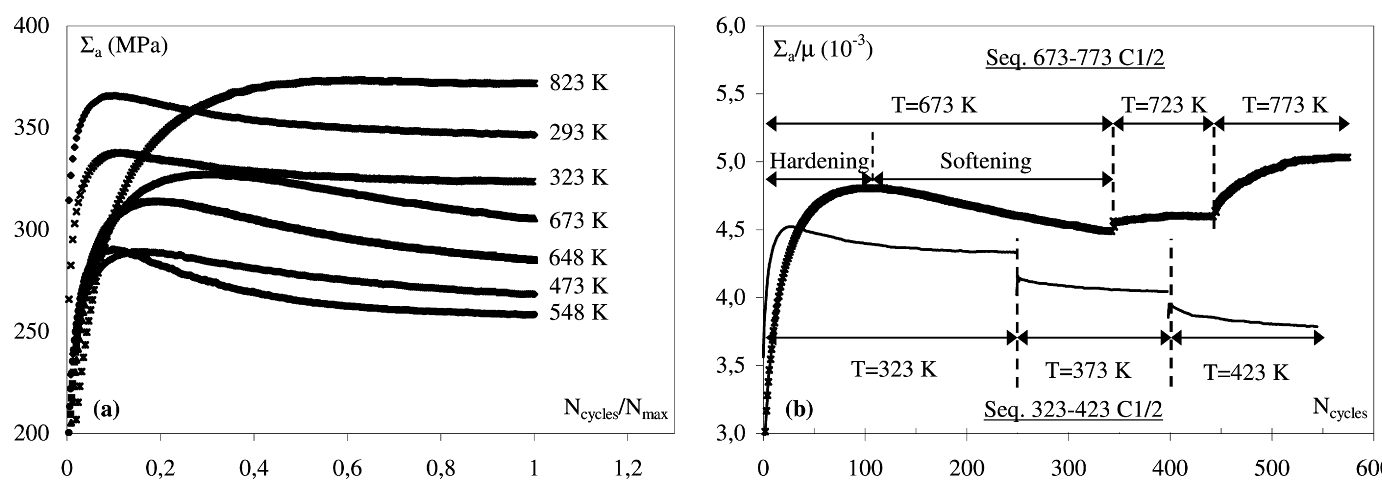

Fig. 4. Stress amplitude variation *versus* normalized cyclic number (N_{max} is the total number of cycles of the test) for isothermal tests (a) and stress amplitude *versus* cyclic number during anisothermal full sequential tests (b).