# Ratcheting fatigue behaviour of a sensitized austenitic stainless steel (non-conventional)

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## Introduction

The aim of this investigation is to study the effect of thermal sensitization on the tensile and ratcheting fatigue behaviour of a non-conventional austenitic stainless steel (X12CrMnNiN17-7-5). The steel is known as non conventional since it contains relatively lower Ni percentage as compared to the traditional 304 grade of steel and hence cheaper to manufacture. Austenitic stainless steels are prone to thermal sensitization which has deleterious effect on the mechanical properties of any component made of it. This particular steel is potentially used in automobiles as well as in structural applications where chances of fatigue failure cannot be ruled out. One of the new research domains of fatigue studies of materials is fatigue under asymmetric cyclic loading. This phenomenon is known as ratcheting where plastic strain gets accumulated in a component and thereby reduces low fatigue life of the component. Therefore it is crucial to recognize the combined adverse effects of degree of sensitization* (DOS) and ratcheting behavior of engineering components or structures to safe guard them during their service life.

## Experimental procedure

The solution annealing (SA) heat treatment was imparted to the as received rods (dia. 16mm) by holding these at 1050°C for one hr followed by water quenching. A few of these rods were imparted thermal sensitization at 750°C for different soaking durations of 5, 10 and 15 hrs which also were followed by rapid water quenching. The heat treated rods were machined to fabricate tensile samples as per ASTM standard E8M and tensile testing is conducted using universal testing machine (UTM). The fractured surfaces were examined using scanning electron microscope. The fatigue specimens were prepared as per ASTM E606 and the tests were performed using ±100 kN UTM. All the fatigue tests were done at a constant stress rate of 50 MPa/s and for 150 cycles. The mean stress ($\sigma_m$= 30 MPa) was kept constant while stress amplitudes ($\sigma_a$= 200, 240 and 270 MPa) were varied after every 50 cycles.

| Heat Treatment | Yield Strength (MPa) | Tensile Strength (MPa) | % uniform elongation |
|---|---|---|---|
| SA | 411 | 815 | 49 |
| Sensitized 5 hrs | 242 | 797 | 45 |
| Sensitized 10 hrs | 225 | 794 | 38 |
| Sensitized 15 hrs | 170 | 793 | 30 |

## Results and analysis

The microstructure of the selected steel in solution annealed condition reveals that the steel owns nearly equiaxed austenite grains with annealing twins throughout the matrix as shown in Fig.1a whereas, the sensitized microstructures (Fig. 1b, c and d) show loss of directionality with increased sensitized grain boundaries with increase in DOS. The results of tensile tests depict marginal decrease

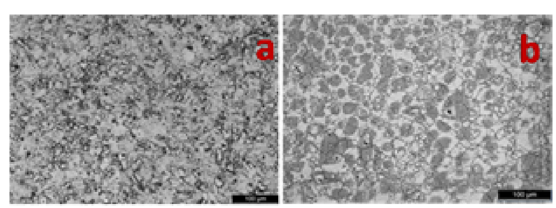


**Figure 1: Micrographs of the investigated steel: (a) SA at 1050°C for 1 hr, sensitized at 750°C for (b) 5 hrs,**

*Degree of sensitization (DOS) refers to the soaking period of sensitization heat treatment

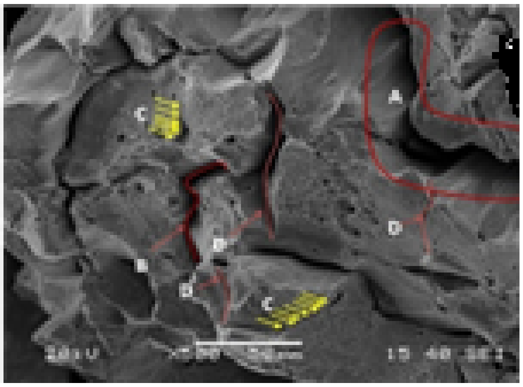

Figure 2: Fractograph of the sensitized steel

in tensile strength with significant decrease in yield strength. The values are provided in Table 1. From the fractographic studies, SA specimen reaveals dimple structure whereas sensitized specimens show de-cohesion between the particle and the interface occurred at the grain boundary due to the solute precipitation. The fracture surface of the sensitized steel carries the signature of sensitization in terms of grain boundary cracking followed by transgranular fracture. However in sensitized samples the tendency for void formation is more at the grain boundaries and these combines to form intergranular cracks. It can be noticed that with the increase in DOS the amount of intergranular cracks increases thus decreasing the transgranular cracks, as also observed by Ghosh et al. [1]. The results of ratcheting tests done with the SA and sensitized samples are presented in terms of stress- strain hysteresis loops and ratcheting strain ($\varepsilon_r$) *vs.* number of cycles (N) in Fig. 3 and Fig. 4 respectively. Typical hysteresis loop for the sensitized (5 hrs) sample is shown in Fig. 3. Typical plots of $\varepsilon_r$ *vs.* N for SA and sensitized steels are shown in Fig. 4. The results indicate that ratcheting strain monotonically increases with increase in number of cycles for any $\sigma_m$-$\sigma_a$ combination, in accordance with earlier investigations on cyclically hardenable material like austenitic stainless steel [2]. The rate of ratcheting strain increases after each increment of stress amplitude (i.e. after each 50 cycles). It can also be inferred that with increase in DOS the value of $\varepsilon_r$ decreases. This is due to increased amount of grain boundary segregation with sensitivity as it actually restricts the plastic deformation process and dislocation activity.

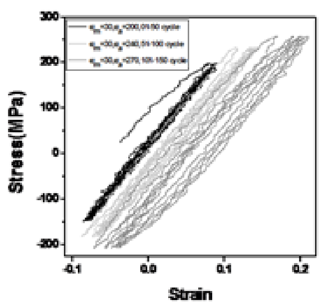


Figure 3: Typical hysteresis loop for a sensitized (5hrs) sample.

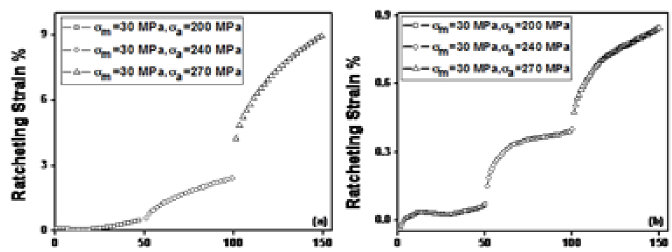


Figure 4: Typical plots of $\varepsilon_r$ *vs.* N for (a) SA and sensitized for (b) 5hrs

**References**

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