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Procedia Engineering 74 (2014) 368 – 375

Procedia Engineering

www.elsevier.com/locate/procedia

XVII International Colloquium on Mechanical Fatigue of Metals (ICMFM17)

# Effect of prestrain and stress rate on Bauschinger effect of monotonically and cyclically deformed OFHC copper

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**Abstract**

The effect of monotonic and cyclic deformation on the evolution of back stress vis-à-vis Bauschinger effect due to different amounts of unidirectional plastic deformation in annealed OFHC copper has been investigated. It is observed that for the same amount of prestrain the back stress evolution and the corresponding Bauschinger phenomenon depend upon the mode of deformation. It is found that higher back stress develops in case of monotonic deformation as compared to ratcheting deformation for same amount of unidirectional prestrain. It is also found that the effect of stress rate on the change of Bauschinger parameters is comparatively less than the effect of increasing prestrain in both types of deformation.


Selection and peer-review under responsibility of the Politecnico di Milano, Dipartimento di Meccanica

*Keywords: Bauschinger effect; back stress; tensile; ratcheting; stress rate.*

## 1. Introduction

During monotonic or cyclic plastic deformation dislocations are piled up against different kinds of barriers. As a result, back stress is generated, which reduces the yield stress of a material when the direction of deformation is reversed. Such reduction of yield stress in the reverse loading direction due to prior forward loading in the plastic regime is known as Bauschinger effect. There are two kinds of mechanisms behind the Bauschinger effect. In one

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Selection and peer-review under responsibility of the Politecnico di Milano, Dipartimento di Meccanica
doi:10.1016/j.proeng.2014.06.281

mechanism, during plastic deformation dislocations accumulate at barriers and produce both long range and short range interactions and pileups. As a result back stress is developed in the material, which assists the movement of dislocation in the reverse loading direction. In the second mechanism, when the loading direction is reversed, dislocations of opposite sign are produced from the same source, attract each other and annihilation of dislocations occur. Since strain hardening is related to dislocation density, reducing the number of dislocations reduces the strength. The net result is that the yield strength in reverse loading direction becomes lower than what is observed in case of forward loading direction.

According to the back stress theory of Bauschinger effect the increase of dislocation density with increases in amount of prestrain results in more and more dislocation pile-ups which develop more back stress and consequently the Bauschinger parameters are influenced [1-5]. But once a dislocation becomes immobile by interaction, it does no longer contribute to back stress in a dislocation pileup. With increase in prestrain the number of mobile dislocation may be decreased due to more and more dislocation interaction and possible formation of more stable dislocation structure. Therefore increasing the amount of prestrain the back stress increases upto a certain level of prestrain and then decreases or saturates depending upon the number of mobile dislocation present in the material [2, 3, 6]. Several investigators reported that mobile dislocation density and dislocation velocity are proportionally related to the strain rate or stress rate of deformation. With increase of the stress rate/strain rate yield strength and flow stress of the material increase due to higher mobile dislocation density and dislocation velocity [7-12] and thus resulting in more dislocation pile-ups. In this context it would be expected that increasing the stress rate of deformation higher back stress will be developed and consequently the Bauschinger parameters of the material is influenced when the change in stress rate is sufficient to significantly alter the work hardening behavior of that material [1, 13-18].

The Bauschinger behaviour of a material is commonly studied by tension loading to certain percentage of unidirectional strain, followed by reversal of loading direction and comparing the flow behaviour of the material in the reversed loading direction with that of forward loading direction. But, the effect of asymmetric cyclic plastic deformation (ratcheting), which also produces unidirectional permanent strain, on the Bauschinger behaviour has not been received any attention. The objective of the present investigation is to make a comparative study of the effect deformation mode, monotonic and cyclic, and the rate of deformation on the Bauschinger behaviour of annealed OFHC copper. Specifically, the effect of different amounts of unidirectional prestrain under monotonic and ratcheting deformation and stress rate on Bauschinger behaviour have been investigated.

**Nomenclature**

| | |
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| $\beta_\sigma$ | Bauschinger stress parameter |
| $\beta_h$ | Bauschinger hardening parameter |
| $\beta_\varepsilon$ | Bauschinger strain parameter |
| $\beta_E$ | Bauschinger energy parameter |
| $\sigma_P$ | Maximum pre stress |
| $\sigma_{y1}$ | 0.2% offset yield stress |
| $\sigma_{y2}$ | Yield stress in the direction of reverse strain (0.05% strain) |
| $\varepsilon_P$ | Pre-strain |
| $\varepsilon_r$ | Bauschinger strain, the strain in the reverse direction corresponding to the point of reverse stress equal to the maximum pre stress ($\sigma_P$) |
| $E_P$ | Energy spent during pre-strain |
| $E_s$ | Energy saved during reverse straining due to the Bauschinger effect |
| $\sigma_b$ | Back stress |
| $\sigma_{ef}$ | Effective stress |
| $\sigma^*$ | Thermal part of effective stress |
| $\sigma_\mu$ | Athermal part of effective stress |