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Cyclic behavior of cold-formed polycrystalline copper

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Abstract – The influence of the forming process (rotary swaging or wire drawing, with 87% area reduction) on the cyclic mechanical properties of cold-formed electrolytic copper bars is evaluated. Although apparently similar products were obtained, their microstructures and defect structures are affected by the distinct deformation paths associated with these routes. Strain-controlled fatigue tests were conducted and the Cottrell's scheme was employed to separate the flow stress into a friction stress and a back stress from the hystheresis loops. The wire drawn bar samples presented higher stresses at saturation than the rotary swaged ones for the strain amplitudes of 0.5% and below. Moreover, the fatigue lives of the former condition were significantly higher than those of the latter.

The cyclic stress-strain response and fatigue life of metals and alloys can be influenced by the grain morphology, by microstructural instabilities associated with cyclic softening and formation of shear bands [1]. The assessment of fatigue behavior of materials with basis on strain-controlled tests plays a key role in this field. Moreover, it is widely recognized that the shapes of hystheresis loops can furnish information about the internal stresses [2]. In the last decades, copper has been widely employed in fundamental researches on metal fatigue mechanisms [3]. The aim of the present work is to evaluate the influence of the forming process on the cyclic mechanical properties of cold-formed electrolytic copper bars. A commercially pure copper annealed cylindrical bar with 25 mm diameter was divided into two parts and cold-formed to 9 mm diameter (87% area reduction), each part by a specific process: rotary swaging (RS) and wire drawing (WD). Although apparently similar products were obtained by these routes, their microstructures and defect structures are affected by the distinct deformation paths associated with the forming processes. Fully reversed low cycle fatigue tests were conducted at room temperature under total strain control with a frequency of 0.2 Hz and sinusoidal waveform. Hystheresis loops were recorded for further analysis.

It was observed that all of the samples experienced cyclic softening with a tendency to saturation. The shape and size of the hystheresis loops for both material conditions were identical for the higher strain amplitudes. However, the wire drawn bar samples presented higher stresses at saturation than the rotary swaged ones for the strain amplitudes of 0.5% and below (Fig. 1). Moreover, the fatigue lives of the former condition were significantly higher than those of the latter. The strain-life curves (Fig. 2) and the cyclic properties for both material conditions (Tab. 1) were determined. The Cottrell's scheme was employed to separate the flow stress into a friction stress and a back stress from the hystheresis loops. The overall softening behavior was a result of fluctuations in internal stresses, the back stress being at a higher level than the friction stress for all of the experiments (Fig. 3).

Table 1: Cyclic Properties or Polycrystalline Copper.

Material Condition	σ'_f (MPa)	b	ε'_f	c
RS	344.3	-0.0596	0.129	-0.540
WD	404.8	-0.0670	0.322	-0.653

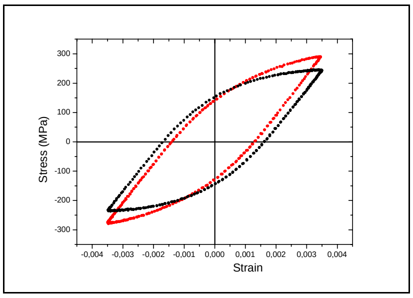

Figure 1: Stable hysteresis loops: RS (black) and WD (red) material conditions.

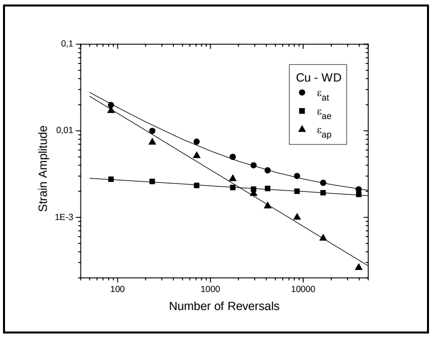

Figure 2: Strain-life curves of WD material.

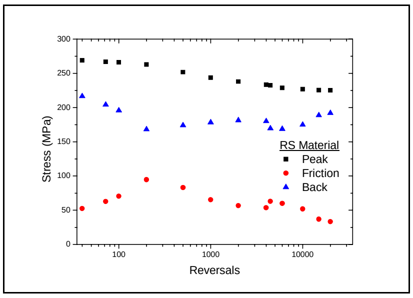

Figure 3: Internal stresses evolution, RS material, 0.21% strain amplitude.

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