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Optimisation of post-drawing treatments by means of neutron diffraction

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Abstract

The mechanical properties and the durability of cold-drawn eutectoid wires (especially in aggressive environments) are influenced by the residual stresses generated during the drawing process. Steelmakers have devised procedures (thermomechanical treatments after drawing) attempting to relieve them in order to improve wire performance. In this work neutron diffraction measurements have been used to ascertain the role of temperature and applied force – during post-drawing treatments – on the residual stresses of five rod batches with different treatments. The results show that conventional thermomechanical treatments are successful in relieving the residual stresses created by cold-drawing, although these procedures can be improved by changing the temperature or the stretching force. Knowledge of the residual stress profiles after these changes is a useful tool to improve the thermomechanical treatments instead of the empirical procedures used currently.

Keywords: Residual stresses; Neutron diffraction; X-ray diffraction (XRD); Eutectoid steels; Cold-drawing

1. Introduction

Eutectoid cold-drawn steels can be seen as – in present day terminology – nano-composite, nano-laminate materials, endowed with outstanding properties of strength and toughness that are still amazing to the modern metallurgist and materials engineer [1,2]. Pearlitic cold-drawn wires and strands are the active tendons in prestressed concrete structures, support the tensile stresses in suspension and stayed bridges, and form the cables in mine shafts and off-shore petroleum production [3–5].

Cold-drawn steel wires suffer a large plastic deformation during the drawing process. After drawing, strains tend to recover but if hampered somewhere by previous plastic deformation, a field of residual strains – and hence, stresses – may appear [5–8]. The mechanical properties of cold-drawn eutectoid wires are controlled largely by the microstructure developed during processing [1,2] and, to some extend, by the residual stresses generated in the drawing process [3]. It is known that such stresses influence stress relaxation losses over time [9], subcritical crack propagation in fatigue life [10,11], and environmentally assisted cracking [12,13].

The role of these residual stresses is of such significance that steelmakers have devised procedures – still mainly heuristic – to try to control them after cold-drawing. In the case of the prestressing industry, they attempt to modify the stress fields resulting from drawing by heating and/or stretching the wires [14].

The purpose of this paper is to provide original data on the effect of different thermomechanical post-drawing treatments on the residual stresses. Such results are based on neutron diffraction experiments that have provided data until now unattainable.

2. Experimental

2.1. Research programme

The thermomechanical treatments applied by steelmakers to relieve residual stresses during cold-drawing are based on stretching and heating the wires during a short time period. This procedure – commercially secret – improves the mechanical properties and enhances the durability of steel wires in the presence of aggressive environments.

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To ascertain the role of temperature and tensile stress – during post-drawing treatments – on the residual stresses, five rod batches with different post-drawing thermomechanical treatments were produced for this research: the first one (called S, standard) was made by stretching the rods at 0.50 of the rupture load, at a temperature of 400 °C. The second and third batches were manufactured by stretching at different values, one at 0.38 of the rupture load (called LF, low force) and another one at 0.64 of the rupture load (called HF, high force), while keeping rod temperature at 400 °C. The fourth and fifth batches were processed at different temperatures while maintaining the stretching force at 0.50 of the rupture load: the fourth was heated at 330 °C (called LT, low temperature) and the fifth heated up to 460 °C (called HT, high temperature). In addition, the "as-drawn" sample (called D) was also investigated. A summary of these thermomechanical treatments and its notation is given in Table 1.

Table 1
Parameters of the thermomechanical heat treatments

Batch	Treatment	Force (F_{max}, %)	Temperature (°C)
D	"as-drawn"		
S	Standard treatment	50	400
LF	Low force	38	400
HF	High force	64	400
LT	Low temperature	50	330
HT	High temperature	50	460

2.2. Material

The samples were supplied by EMESA (Arteixo, La Coruña, Spain). The chemical composition of the steel used was 0.815 C, 0.231 Si, 0.642 Mn, 0.012 P, 0.008 S, 0.044 V and 0.221 Cr (mass%). The initial rod (12 mm diameter) was subjected to six drawing passes to reach a final diameter of 7.0 mm. The schedule of diameters (% reduction in area) of the six drawing dies was: 11.6 mm (7%), 10.4 mm (20%), 9.3 mm (20%), 8.5 mm (18%), 7.8 mm (16%) and 7.0 mm (20%). The drawing velocity was 44 m/s. Temperature was controlled during the process and the maximum value measured on the wire surface at the exit of the last die was 197 °C.

Longitudinal and transverse cross-sections were prepared for metallographic analysis. After polishing, samples were etched with Nital 2%. Before SEM observation, a thin Au–Pd film was deposited on the surface of the samples by sputtering. In the micrographs obtained by SEM (Fig. 1) it can be seen that the rod microstructure is fully pearlitic, as corresponds to the eutectoid point (0.8% C), with alternating nanosized ferrite (α-Fe) and cementite (Fe_3C) lamellae (interlamellar spacing around 100 nm). This is typical of cold-drawn eutectoid steel, the lamellae being aligned in the drawing direction, which coincides with the rod axis [14]. The different post-drawing thermomechanical treatments do not produce visible changes in the microstructure. This is why only micrographs corresponding to

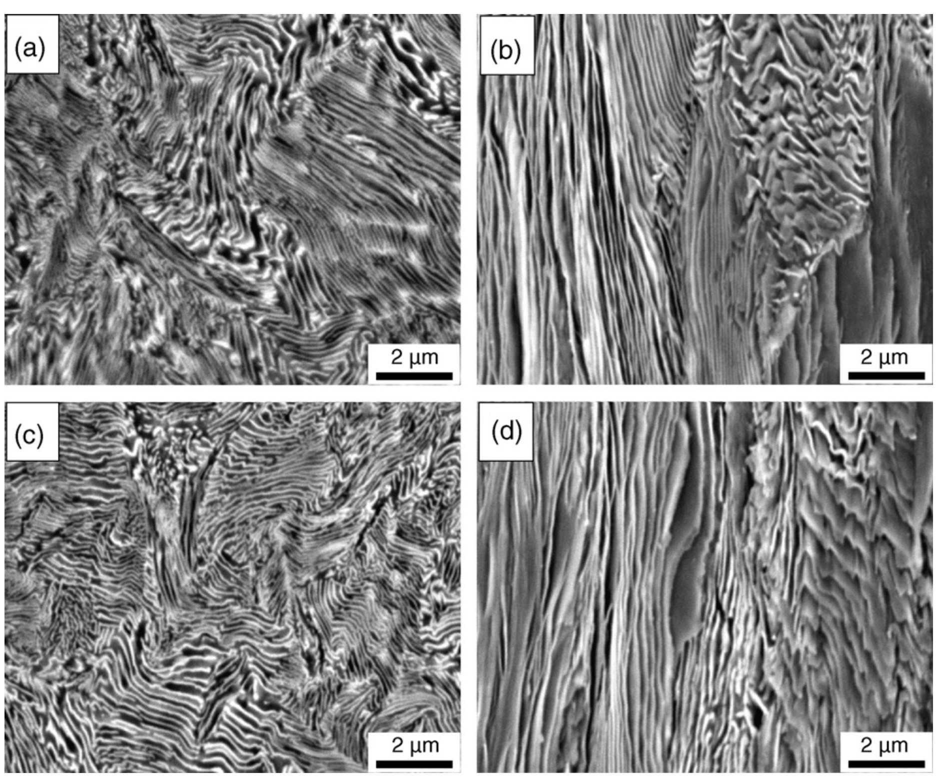

Fig. 1. Microstructure of the eutectoid steel rods. Standard (S) treatment: (a) transverse cross-section and (b) longitudinal section; and high-temperature (HT) treatment: (c) transverse cross-section and (d) longitudinal section. The drawing direction (parallel to the rod axis) is perpendicular to the paper in (a) and (c) and lies in the paper (vertical direction) in (b) and (d). The light features correspond to the cementite and the dark regions between cementite lamellae are occupied by ferrite, which is etched by the reagent employed (Nital 2%).