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Effect of Hydrogen Release at Room Temperature on Ductility of a Steel Wire Rod for Pre-stressed Concrete

C. J. Carneiro(1), M. B. Mansur(2), P. J. Modenesi(2) and B. M. Gonzalez(2) *

(1) Gerdau Açominas, Ouro Branco, MG, Brazil
(2) Departamento de Engenharia Metalúrgica e de Materiais, Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brazil, E-mail: gonzalez@demet.ufmg.br
* Corresponding author.

Abstract – The reduction of area variation with stock time of a high carbon steel wire rod for pre-stressed concrete, after rolling and controlled cooling was studied in an 11-mm diameter wire rod produced without vacuum degassing. Hydrogen content and reduction of area for storage times up to 960 hours were determined. Hydrogen content decreased from 1.85 ppm immediately after cooling to between 0.55 and 0.60 ppm after 216 hours while reduction of area changed from 20% to about 37%. It was shown that the process responsible for the increase in ductility with time of storage is the release of hydrogen by trap-controlled diffusion.

Steel for pre-stressed concrete strand is produced from hot-rolled high carbon steel wire rods that should be drawn to the required diameter. It is well known that, during this operation, hydrogen has a harmful effect on ductility. In order to control steel ductility and ensure its drawing, a reduction in area greater than 30% is usually required in the tensile testing of the rod. Usually, vacuum degassing is used during steelmaking to reduce hydrogen content of the steel and guarantee an adequate ductility level to the rod. The present work aims to relate the variation of hydrogen content and reduction of area with holding time at room temperature of high-carbon wire rods used in the fabrication of steel ropes for pre-stressed concrete applications. It also intends to contribute to the understanding of the mechanisms controlling room temperature hydrogen release from steel.

Commercial grade steel was produced as a hot-rolled and controlled-cooled wire rod 11 mm diameter. Metallographic samples of the cross section of the wire were examined by SEM to characterize its microstructure. 400-mm long samples of the wire rod were stored at room temperature immediately after being cooled in the Stelmor® for 72, 120, 144, 216, 288, 480, 600, 720 and 960 hours. These samples were used to measure the variation of hydrogen content and reduction of area in the tensile test with the storage time. Tensile testing was done using a 500 kN Shimadzu machine in 400-mm long specimens using a gauge length (110 mm) ten times longer than the specimen diameter and a strain rate of $3x10^{-3}$ s^{-1}. The reduction of area at necking, Z, were determined and hydrogen content was measured in a LECO RH 402 spectrometer.

The reduction of area, Z, increases with the storage time from its initial value (20%) to about 37% after being stored for 216 hours at room temperature (Figure 1) while the variation of hydrogen of the steel, C_t, reduces with its storage time from its initial value, 1.85 ppm, to between 0.55 to 0.60 ppm after a storage time of 216 hours (Figure 2). To analyze the escape of hydrogen by diffusion in the wire rod and based on the theoretical approach presented by Crank [1], hydrogen concentration in a long cylindrical sample (length, L, much greater than its diameter, d) was obtained by solving the theoretical model equation which has the same format of fitted equation shown in Figure 2. The analysis of the variation of hydrogen content in the steel during its storage indicated that hydrogen escape is controlled by hydrogen diffusion with reversible traps. This is important from the technological point of view because, for trap-controlled diffusion, the hydrogen concentration, C_t, thus the reduction of area, Z, depend on the sample dimension (the bar diameter), while for thermal desorption the sample dimension does not affect C_t and Z. The obtained value of the activation energy for this process suggests that such traps may be $Fe\text{-}Fe_3C$ interfaces.

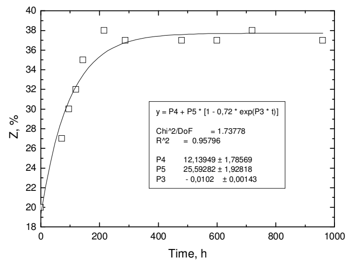

Figure 1: Variation of the reduction of area, Z, with the storage time at room temperature.

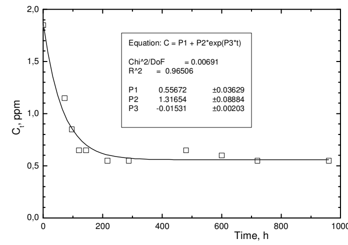

Figure 2: Variation of the hydrogen content, Ct, with the storage time at room temperature.

References

[1] J. Crank: 'The Mathematics of Diffusion', 2nd edn, 414; 1975, England, Oxford Univ. Press.