New steel stress coupons based on induction heating and consequent quenching

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In this work we demonstrate our new method to prepare steel coupons including various residual stresses, up to the corresponding yield point, to determine the magnetic stress calibration (MASC) curve of the steel grade under test. The method is based on the generation of a gradient temperature profile across a parallelepiped piece of steel when it is heated by an induction coil or a straight conductor. The generated eddy currents in the steel coupon provide this temperature gradient, which is transformed to residual stress gradient by quenching in water or oil. Stresses are determined by the X-Ray diffraction in the Bragg – Brentano arrangement, while the corresponding magnetic properties are the magnetic field components at the surface of the steel coupon, using 3D AMR field sensors. This method is repeatable and allows for closer approach to the yield point of the steel under test. Therefore it is suitable for inter-laboratory comparison tests in this field.

Keywords: Residual stresses; Induction heating; AMR field sensors; Magnetic stress calibration (MASC) curves

1. Introduction

During the last two decades, our group has developed a methodology to provide the dependence of magnetic properties on residual stresses from a single steel coupon, i.e. from a steel parallelepiped, cut in two pieces and welded autogenously. Provided that the two steel parts are maintained in a stable position, the cooling-down process in the heat affected zones and the fusion zone after welding, results in a stress profile from minus yield point up to plus yield point of the steel under test. Although we succeeded to determine the so called Magnetic Stress Calibration (MASC) curves with this method, it has been proven difficult to make this technology repeatable and transferable. This issue has been resolved by using a new methodology, according to which the steel coupon is locally heated by induction heating process.

2. Results and discussion

Steel coupons of different steel grades have been tested, namely S235 and AISI 4130, used for shipping applications (and not only), AISI 1008 allowing for high permeability applications, as well as Cr-Mo steels. All steel coupons underwent heat treatment at 400°C for 1 hr with consequent slow cooling down process to release as much as possible the localized residual stresses. Consequently, a straight, water cooled, 6mm diameter copper tube is set on top of the steel coupon, transmitting 30 A current at a frequency of 30 kHz. This way, the eddy currents at the vicinity of the copper tube offer a temperature that decreases from the middle heating point towards the two ends of the coupon, due to the relatively low thermal conductivity of (magnetic) steels.

Monitoring the maximum temperature T_{max} of the steel coupon by an IR camera, after T_{max} reaches one third of the steel melting point, the steel coupon is inserted in room temperature water or oil, dependent on the steel grade, maintaining its geometrical shape by two ceramic plates forcing it to do so. Thus, the temperature gradient is transformed to stress gradient, allowing for repeatable generation of residual stresses in this heat affected zone of the steel coupon. Then, residual stresses in different points-areas of the steel have been determined, by using the X-Ray Bragg – Brentano method. In parallel, the three magnetic field components at the same points-areas at the surface of the steel have been also determined. Thus the pair of values of residual stress and field components are determined for different points-areas of the steel. Figure 1 demonstrates an indicative MASC curve of a 6 mm thick 42CrMo4 steel grade, while Figure 2 demonstrates the MASC curve of an electric steel lamina.



Figure 1. MASC curve based on the dependence of the vertical field component of the AMR sensor in μT on the residual stresses of a 42CrMo4 steel.



Figure 2. MASC curve based on the dependence of the vertical field component of the AMR sensor in μT on the residual stresses of an electric steel.