

EFFECT OF PLASTIC DEFORMATION AND ITS LOCALIZATION ZONES ON MAGNETIC CHARACTERISTICS OF CARBON STEEL

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The development of methods for estimating internal stresses in steel components is one of the urgent problems of nondestructive testing since, during operation of metal constructions, these stresses can be added to applied stresses, and the total stresses may exceed allowable values. To a large extent, the breaking strength of steel is determined by local concentrations of internal stresses, which are potential crack nuclei. At present, magnetic methods, in particular, in using attachable electromagnets find ever-widening application for estimating the strained state of steel components. The use of these methods is based on correlations, which, in particular, result from magnetostriction and magnetoelastic effects, between magnetic characteristics of a metal and internal stresses induced in it by plastic deformation.

In this paper we report results of investigation into the hysteretic properties of carbon steel subjected to plastic deformation by uniaxial tension. As the subjects of inquiry, we used a planar tensile sample made of normalized steel 45 having a gage length of 95 mm, a width of 30 mm, and a thickness of 1.8 mm, which, after plastic deformation, exhibits clear bands of plastic-deformation localization (PDL bands), which are located near the fillets connecting the test portion with the grip section. Figure 1 shows images of the left and right parts of the specimen with PDL bands.

To measure the coercive force, we used a U-shaped attachable electromagnet having a 16 x 4 mm pole cross section and 8-mm pole separation; the measuring coil is wound around the magnetic-core yoke leg. A signal from the measuring coil was fed to the magnetic-flux measuring channel of magnetic-measuring system MIK-1; after that, the signal was integrated and recorded in the form of a dependence of the electromotive force on the magnetization reversing current

Magnetic hysteresis loops were measured along two directions, namely, along and perpendicular to the tension direction. The necessity of the measurements along two mutually perpendicular directions is related to the possible anisotropy of stresses induced by plastic deformation. The maximum magnetizing current was 2 A. This current gives the maximum magnetizing field, which exceeds the coercive force of specimen by an order of magnitude, and magnetic hysteresis loops close to major ones. These data were used to determine the demagnetizing current I_c , which is proportional to the coercive force.

The Barkhausen noise parameters, such as the root-mean-square (rms) voltage U and the number of Barkhausen jumps per magnetization reversal cycle were recorded by a MICROSCAN 600 (STRESSTECH GROUP) digital analyzer of Barkhausen noise. As a transducer, an attachable sensor having an 8 x 9 mm pole cross section and 9-mm pole separation was used. In this case, in accordance with the thickness of plates and their magnetic properties, we optimized the magnetization-reversing current parameters, such as the amplitude and frequency, which were 120 mA and 20 Hz, respectively.

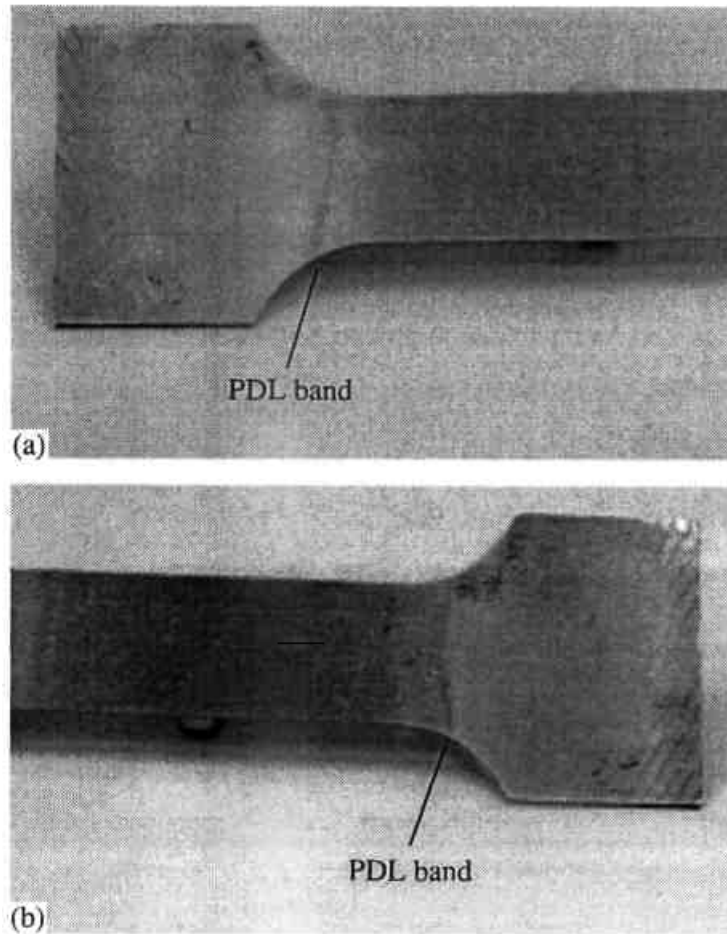


Fig. 1. A specimen with PDL bands: the left part (a), the right part (b).

Studies performed by the Veeco WYKO NT 1100 OPTICAL profiling system showed that an increase in the surface relief of about $20\text{ }\mu\text{m}$ takes place on the PDL bands of the specimen. Moreover, for this region of the specimen, an increase in parameters of surface roughness ($R_a = 1.63\text{ }\mu\text{m}$) is observed as compared to the roughness parameters for the nondeformed portion of the specimen and its test portion, which is free from pronounced PDL bands ($R_a = 1.50\text{ }\mu\text{m}$ and $1.57\text{ }\mu\text{m}$, respectively).

The dependences of the demagnetizing current on the position of the transducer along the plate are shown in Fig. 2a. The measurements were performed both along the whole gage length and for heads of the specimen, which were not deformed during the loading (extreme left and right points in the dependences). As is seen from Fig. 2a, the dependences of the demagnetizing current, which was measured by the attachable electromagnet arranged along and perpendicular to the tension direction, exhibit the opposite behavior. The I_c magnitudes, which were measured by the attachable electromagnet arranged along the tension direction, are maximal at the center of specimen and decrease in approaching the PDL bands. This can confirm the fact that the formation of microdiscontinuities (PDL bands) leads to a decrease in the density of dislocations around them and, therefore, to the relaxation of internal stresses near them. The demagnetizing current measured by the attachable electromagnet arranged perpendicular to the tension direction is minimal at the center of test portion of specimen; the maximum current is observed near the PDL bands.

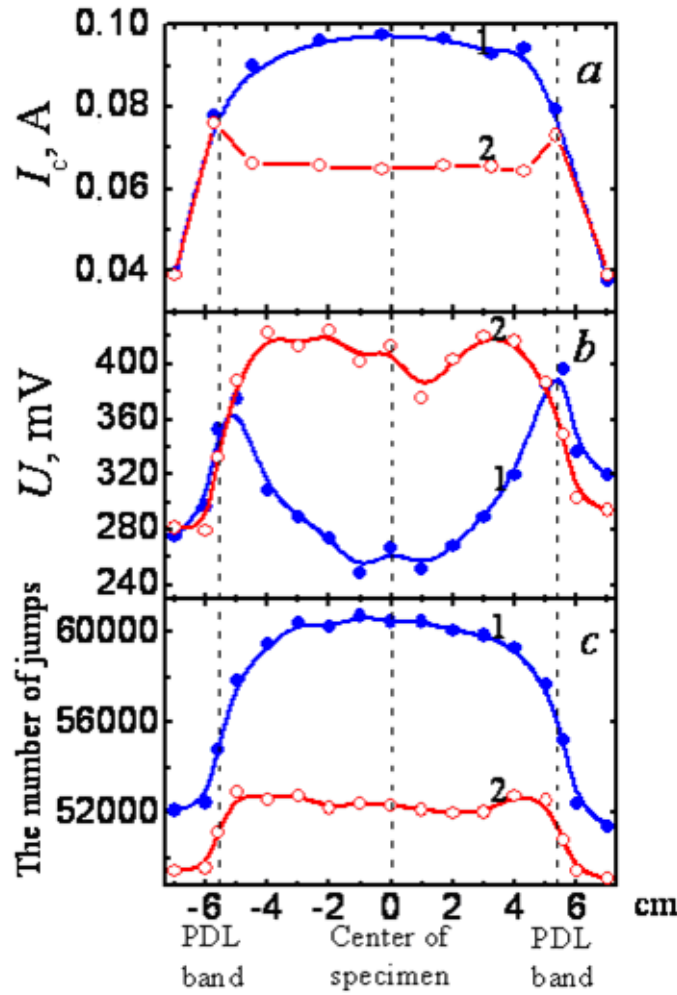


Fig. 2. Dependences of the demagnetizing current I_c (a), rms voltage U (b), and the number of Barkhausen jumps per magnetization reversal cycle (c) on the position of the transducer on the specimen with PDL bands measured along (1) and perpendicular (2) to the tension direction.

Analogous measurements along and perpendicular to the tension direction were performed with the digital Barkhausen noise analyzer. The dependences of the rms voltage U and the number of Barkhausen jumps per magnetization reversal cycle on the position of the transducer on the specimen are shown in Figs. 2b and 2c, respectively.

It is seen from Fig. 2b that, in measuring the U parameter perpendicular to the deformation axis, it is maximal at the specimen center and minimal near the PDL bands. At the same time, in measuring the U parameter along the deformation axis, it is minimal at the specimen center and maximal near the PDL bands. In measuring the rms voltage directly at the PDL bands, the U magnitudes measured by both variants are close to one another. On the whole, the behavior of the U parameter testifies that near the specimen center, the compressive stresses are maximal along the tension direction and tensile stresses are maximal perpendicular to the tension direction.

It follows from Fig. 2c that, in measuring along the tension direction, the magnetization reversal is realized at the expense of a higher number of Barkhausen jumps as compared to that in the case of measuring perpendicular to the deformation direction. This is explained by the fact that, in the initially deformed specimen, the magnetization vectors are mainly in the plane perpendicular to the tension direction, and this is suggestive of prevailing compressive and tensile internal stresses along and perpendicular to the tension axis, respectively.

The identified marked changes in the coercive force and parameters of Barkhausen noise in a range of probable failure of a deformed specimen (in this case, the clearly pronounced PDL bands) can be the basis for developing methods for the magnetic inspection of the prefailure state of constructional steel elements.

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