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DETECTING PLASTIC STRAIN LOCALIZATION ZONES IN STEEL PRODUCTS BY THE RESULTS OF MAGNETIC MEASUREMENTS

INRODUCTION

Plastic deformation in materials is not uniform throughout the volume, but only within separate areas called plastic strain localization zones (PSLZ). This localization of macroscopic strain is one of the main features of the deformation of materials with very different structures. It is in PSLZs that material damage accumulates; they are stress concentrators and, consequently, potential fracture sites. In this regard, developing methods for detecting such zones at the early stages of their formation and evolution is an important problem of nondestructive testing.

As is well known that the coercive force of ferromagnets increases and their initial and maximum magnetic permeabilities decrease with increasing dislocation density, which increases monotonically with the plastic deformation of the material. The inhomogeneity of plastic deformation with the appearance of PSLZs leads to the heterogeneous distribution of the magnetic characteristics of the test product. Due to the increased density of microdefects in strain localization zones, the processes of magnetization and magnetic reversal become significantly more difficult, and this increases the coercive force, decreases magnetic permeability and, accordingly, increases the magnetic resistance of these areas.

Since the distribution of magnetic leakage fluxes on the product surface is correlatively dependent on the distribution of magnetic permeability in the near-surface layers, PSLZs should be characterized by higher values of magnetic leakage fluxes over them. Thus, the inhomogeneity of the distribution of the local magnetic characteristics of the test object and the parameters of the magnetic leakage field on its surface may indicate the existence of PSLZs in this object; this fact can be used to detect potential fracture sites in products made of ferromagnetic materials at the early stages of the formation and development of these fracture sites.

This research is aimed at conducting experiments to determine locally the magnetic properties of plastically deformed carbon steel specimens and to study the topography of magnetic leakage fields on the surface of these specimens in order to test the possibility of detecting strain localization zones by magnetic methods.

MATERIALS AND RESEARCH METHODS

Flat test specimens made of carbon steels with 0.3 % carbon (Russian steel grade St3) and 0.45 % carbon (Russian steel grade 45) were studied. To facilitate the recording of plastic strain localization bands during visual inspection, the specimens were ground, and the roughness parameter R_a did not exceed 0.32 μm. The specimens were plastically deformed by uniaxial tension up to the formation of distinct plastic strain localization bands.

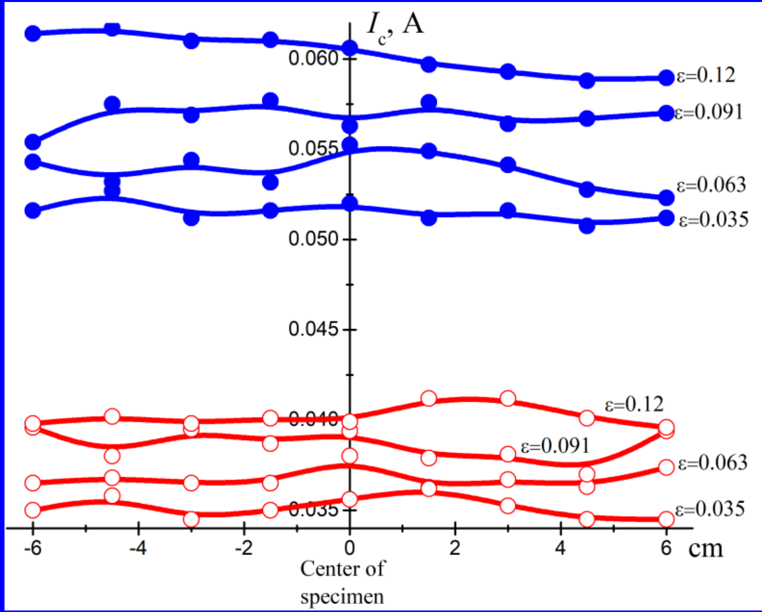
In the process of deformation, the demagnetizing current I_c , corresponding to the zero magnetic flux in the specimen during its demagnetization after magnetization to saturation and therefore proportional to the coercive force of the material, and Barkhausen noise parameters (the rms values of magnetic Barkhausen noise voltage U and the number of Barkhausen jumps per magnetization reversal cycle N) were measured at various points along the entire gauge length of the specimens with the use of attached transducers along and across the tension direction.

A U-shaped attached electromagnet with a pole cross section of 16×4 mm and a distance between the poles of 8 mm, with a measuring coil wound around the middle part of a magnetic core yoke, was used to measure I_c. The signal from the measuring coil was fed to the magnetic flux measuring channel of the MIK-1 magnetic measurement system; thereafter, the signal was integrated and recorded in the form of the dependence of the electromotive force on magnetization reversal current. These data were used to determine the demagnetizing current I_c, which is proportional to the coercive force.

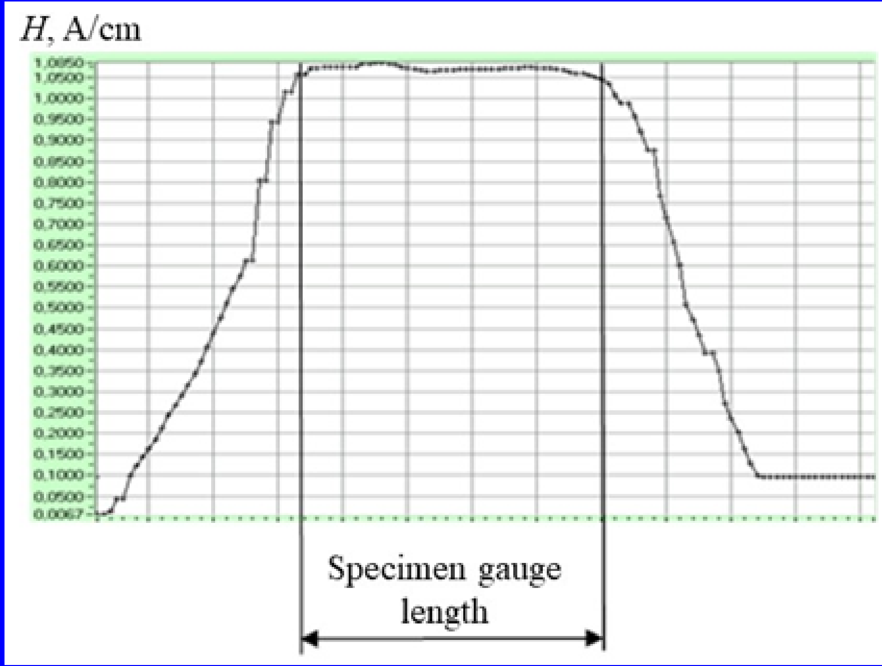
Using a Rollscan 300 digital Barkhausen noise analyzer, we measured the Barkhausen noise parameters. The cross-section of the poles of the attached transducer of the Rollscan 300 analyzer was 8×9 mm, and the distance between the poles was 9 mm. The Barkhausen noise parameters were measured along and across the direction of the applied load.

The topography of the magnetic leakage fields of the specimen in the initial state and the plastically deformed specimens was studied by scanning the surface of the specimens by means of a Magnetoscop 1.069 magnetometer (Institut Dr Foerster GmbH und Co) equipped with fluxgate transducers for recording the tangential and normal components of the magnetic leakage fields. The studies were carried out in the state of residual magnetization after removing the specimens from the testing machine. The specimens were magnetized by means of a magnetizing device based on high energy consuming permanent magnets.

Experiments have shown that, for specimens of both steel grades at the stage of uniform plastic deformation, the distribution of magnetic characteristics and the parameters of magnetic leakage fields are uniform.



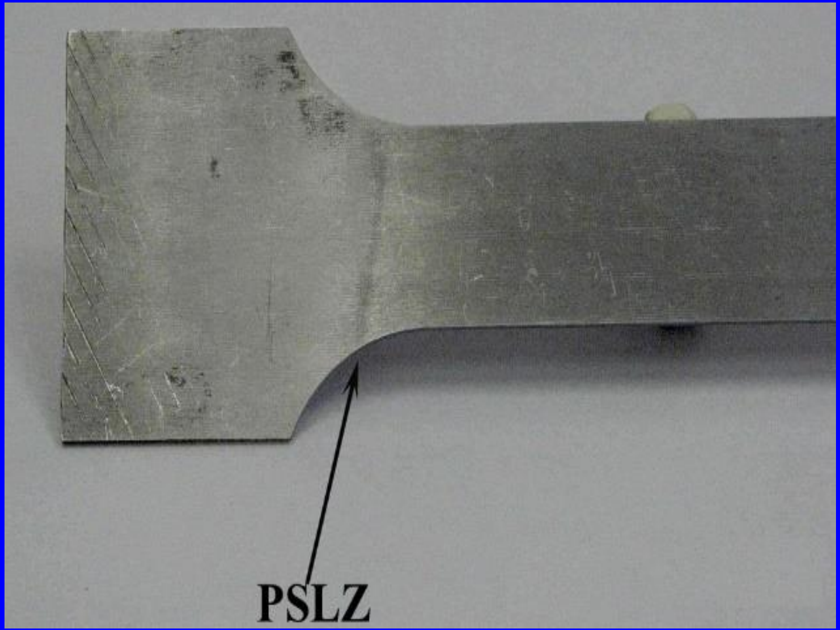
The dependence of demagnetizing current measured along (•) and across the loading axis (o) on the transducer position on the specimens of steel 45 plastically deformed to different values of plastic strain ε. The specimens have no distinct PSLZs.



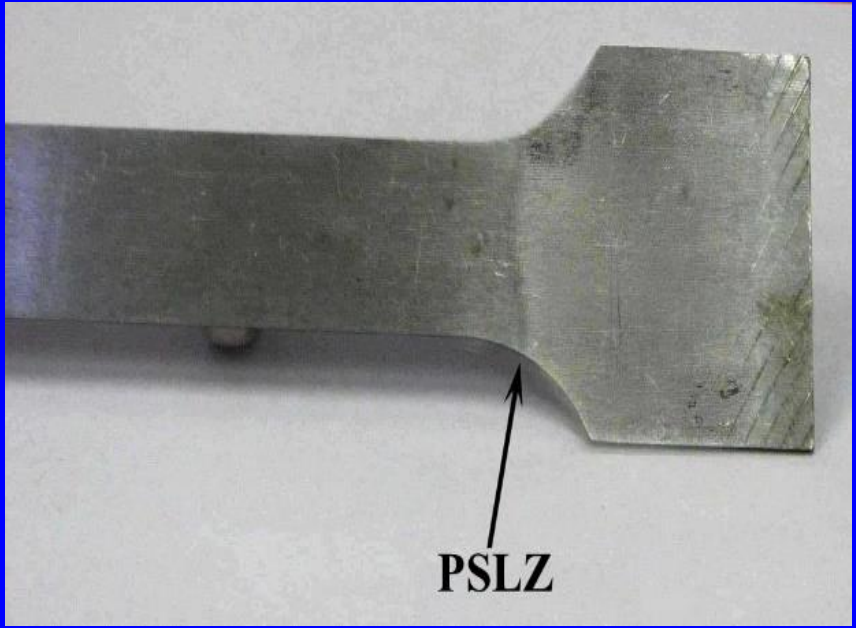
The results of recording the tangential component of the magnetic leakage field on the St3 steel specimen surface before PSLZ formation.

A 45 steel specimen with PSLZs

The left part

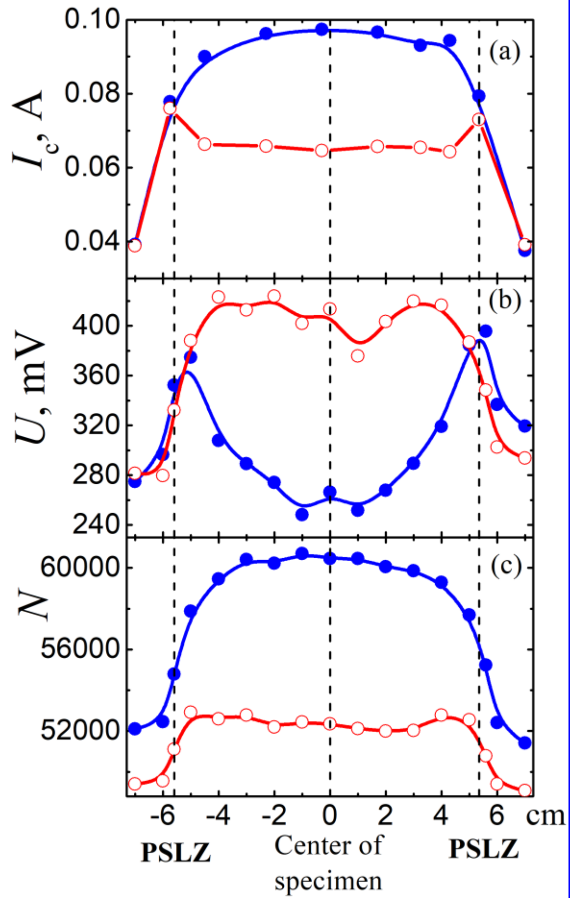


The right part



A different picture was observed on specimens with clearly pronounced PSLZs.

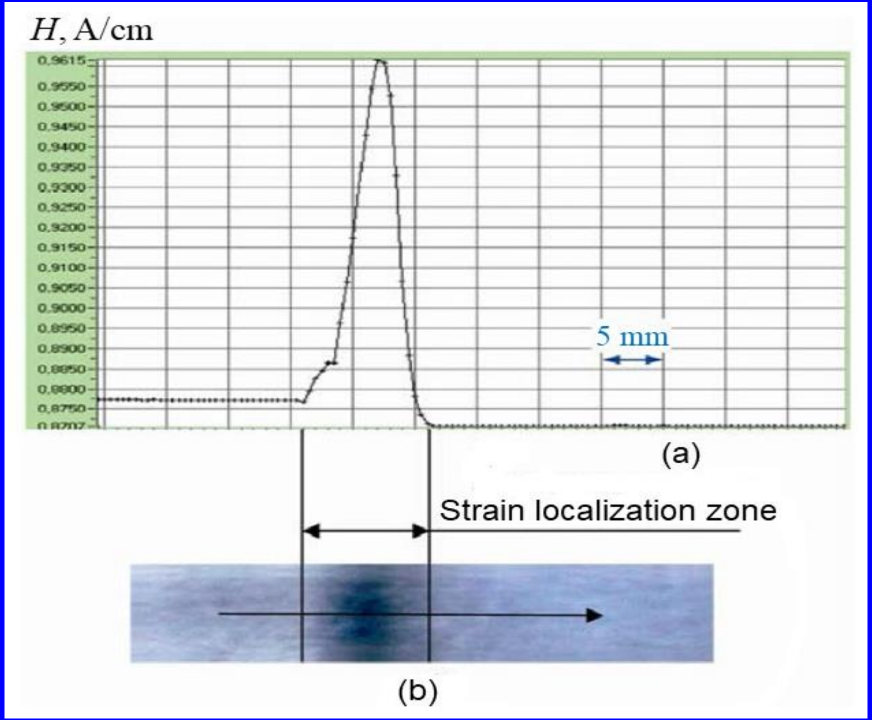
Demagnetizing current *Ic* (a), the rms values of voltage *U* (b), and the number of Barkhausen jumps *N* (c) as dependent on the transducer position on the 45 steel specimen with PSLZs measurements made along and across the loading axis



The dependences of the demagnetizing current I_c on the transducer position along the specimen are presented in (a). The measurements were performed both along the entire gauge length and for the grip sections, which were not deformed during the loading. The dependences of the demagnetizing current, which was measured by the attached electromagnet arranged along and perpendicular to the tension direction, exhibit the opposite behavior. The magnitudes measured by the attached electromagnet arranged along the tension direction are maximal at the specimen center and they decrease when approaching the PSLZ. This can confirm the fact that the formation of microdiscontinuities (PSLZs) leads to the relaxation of internal stresses near them. The demagnetizing current measured by the attached electromagnet arranged perpendicular to the tension direction is minimal at the center of the test portion of the specimen; the maximum current is observed near the PSLZ.

When the Barkhausen noise parameters *U* is measured perpendicular to the deformation axis, it is maximal at the specimen center and minimal near the PSLZ. At the same time, when *U* was measured along the deformation axis, it is minimal at the specimen center and maximal near the PSLZ. When rms voltage was measured directly at the PSLZ, the *U* values measured by both variants are close to one another. On the whole, the behavior of *U* testifies that, after plastic deformation near the specimen center, compressive stresses are maximal along the tension direction and, accordingly, tensile stresses are maximal perpendicular to the tension direction. When measurements are made 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 perpendicular measurements. This is explained by the fact that, in the preloaded specimen, the magnetization vectors lie mainly in the plane perpendicular to the tension direction, and this is suggestive of prevailing compressive and tensile internal stresses along and across the tension axis, respectively.

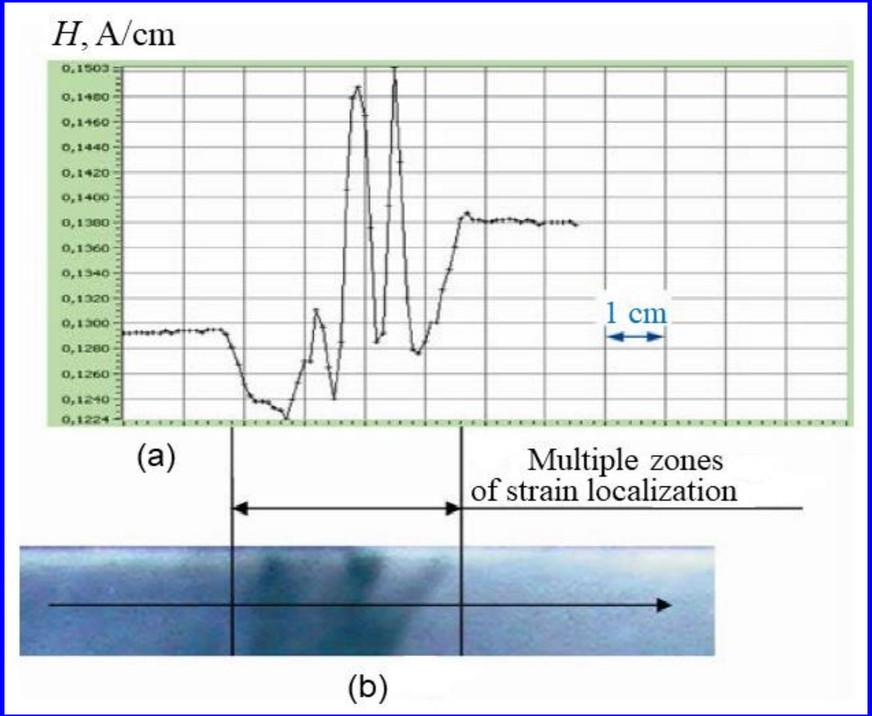
Results of recording the tangential component of the magnetic leakage field on the surface of the magnetized St3 steel specimen containing a single PSLZ and a photograph of the specimen gauge length



The arrow shows the path of scanning the specimen by a fluxgate transducer.

PSLZ formation (b) is accompanied by the appearance of the extreme signal from the fluxgate (a) associated with an increase in the magnetic leakage field over this specimen part. It should be noted that the extrema in the distribution of the tangential and normal components of the magnetic leakage field were reliably recorded even in the presence of a nonmagnetic gap of up to 150 μm between the specimen surface and the fluxgate transducer.

Results of recording the tangential component of the magnetic leakage field on the surface of the magnetized St3 steel specimen containing three bands of plastic strain localization and a photograph of the specimen gauge length



The arrow shows the path of scanning the specimen by a fluxgate transducer.

Three extrema in (a) correspond to the strain localization zones in photo (b). These data confirm the possibility of identifying multiple plastic strain localization zones in products made of ferromagnetic materials.

CONCLUSION

- The analysis of the dependence of demagnetizing current, rms voltage, the number of Barkhausen jumps, as well as the parameters of magnetic leakage field, on the position of an attached transducer on plastically deformed carbon steel specimens has shown that near the plastic strain localization zones there are substantial changes in the measured magnetic parameters. The results obtained have been explained on the basis of the current concept of the anisotropy of internal stresses in plastically pre-deformed materials.
- The identified patterns can be a basis for developing magnetic methods for the early detection of potential fracture sites in the form of strain localization zones in products made of ferromagnetic materials.