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Non-Destructive Testing of Fatigue Damage of Metallic Materials

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---*ABSTRACT*---
The cyclic loading processes inside material induced the changes in microstructure. Those processes can change the state and also the surface properties on the outside layer of material. This possibility led to the idea of detection the fatigue damage level by measuring the hardness at the surface layers. The presented contribution will present results of surface hardness measurements on specimens of four different steels materials which were cyclically loaded.
***KEYWORDS**: fatigue, hardness, measurement, NDT*

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I. INTRODUCTION

The development of numerical computational methods allows the creation of computational models and simulations of an increasing number of actual operating states and situations. The increasing accuracy and complexity of numerical models seemingly reduces the need for experimental measurements. However, direct measurement is and will be irreplaceable in at least three cases:
- for measurement the basic material properties entering numerical models
- for verification of numerical models
- to determine such parameters and performance characteristics that are scattered

This paper is devoted to non-destructive methods of measuring changes in material properties during operation focusing on the possibility of their use in detecting the degree of fatigue damage.

II. NON-DESTRUCTIVE METHODS FOR MEASUREMENT OF MECHANICAL PROPERTIES

Operating performance also leaves traces in the structure of the material that do not appear macroscopically. As non-destructive methods, we will include methods of measurement of material properties and their changes, which allow the continuation of operation of the measured part or structures. At present, five groups of methods are used, namely
• ultrasonic methods
• X-ray methods or laser diffractometry
• micromagnetic methods
• optical methods
• mechanical methods

Ultrasonic methods [1] are based on the transmission of ultrasound waves in the material under consideration and the acceptance of reflection. Evaluated are parameters such as speed, intensity, propagation time, direction, or reflection of reflected waves. Some of this methods measure the relative change of the parameter to the reference state. Other methods measure the absolute value of the measured properties. Ultrasonic methods are sensitive to changing material parameters such as Young's modulus of elasticity, residual stresses, structural changes from local heating, plastic deformation, microcracks and secondary phases.

The micromagnetic methods [1] follow the change of parameters of magnetic hysteresis, which is caused by the movement of Bloch walls (change of the magnetic domain structure). The change of the domain structure is induced by the outer magnetic field after the external mechanical load. Measurable parameters are coercivity, saturated magnetization and remanent flux density, in some methods permeability μ. Known methods are based on Barkhausen noise and magnetic field intensity. Micromagnetic methods are sensitive to material parameters such as tensile strength, hardness, tensile strength, and notched toughness.

Methods using X-ray or X- laser diffraction [1], [2] are based on the measurement of the reflection angle of the transmitted beams from the atomic planes, since the wavelength of these beams is comparable to the dimensions of the crystallographic lattice of solids. They react to elastic stress changes in the surface layers of the material. They are sensitive to residual stress detection, surface tension change, and surface hardness.

Optical methods are represented today by the DIC-method. Digital image correlation is 3D non-contact optical method of experimental acquisition of information about the properties of materials and state of structural elements. To obtain these data digital image registration technique sensing the contrasting stained surface and create a measuring grid. The method allows you to track and quantize the oscillation parameters (the shape of the vibration of the area, the frequency of vibrations) and the strain-stress response to the loading in the 3-D mode.

Mechanical methods follow the changes in the surface hardness of the material or the individual components of the material structure. These methods will be dealt with more closely.

III. PHYSICAL BASES OF MECHANICAL METHODS

Plastic strain is generally determined by the movement of dislocations, the same is true for the case of alternating cyclic plastic strain. Cyclical hardening and softening processes are determined by movement, generation and interactions of dislocations, or other types of grid disorders. Movement of dislocations is further influenced by the presence of precipitates, foreign particles, grain boundaries, etc. It is therefore possible to expect that during the cyclic strain loading not only changes in configuration and density of dislocations will occur, but also changes in the layout and morphology of other types of obstacles. This second type of changes includes, for example, changes in the morphology of precipitates closely related to diffusion processes and further phase transformations induced by cyclic strain.

McGrath and Waldron [3] adverted to significant differences between surface structure and inner structure of metallic materials in the case of cyclically deformed specimens.

On the surface of the samples it is easy to metallographically observe the sliding bands lying along the intersecting surface with the sliding plane from the end of the first stage of the fatigue process. The dislocation structure lying beneath these sliding bands (that is under the surface intrusions and extrusions) differs substantially from the structure in the surrounding matrix which is identical to the internal structure of material [4,5]. From this analysis it is clear that the cyclic loading and the associated fatigue process of the material leave a trace in the surface layer of the material, thereby changing its hardness.

IV. CORRELATION BETWEEN SURFACE HARDNESS AND FATIGUE DAMAGE IN METALLIC MATERIALS

Groups of specimens for testing was made from different types of steels: low carbon steels St50-2 and C55, austenitic steel X10CrNiTi 18-9 and high strength steel 24CrMoV55. All specimens were cyclically loaded by the constant stress amplitude of the alternating push-pull cycle. The hardness of the surface layer was measured periodically after having completed the same number of cycles. The Meopta 568-01 hardness device was used to measure the hardness of the surface layer using a Brinell hardness measurement method with a depth of indentation about 0.06 mm. These depths of indentation did not represent a local notch effect that would cause or accelerate the fatigue process. Fatigue fracture never proceeded from the surface hardness of measurement point (on the contrary, the locality of indentation reinforces the surface, thereby reducing its tendency to fatigue cracks).

Some typical measurement results on various materials with the amplitude of the load cycle load are shown in Figure 1-4.

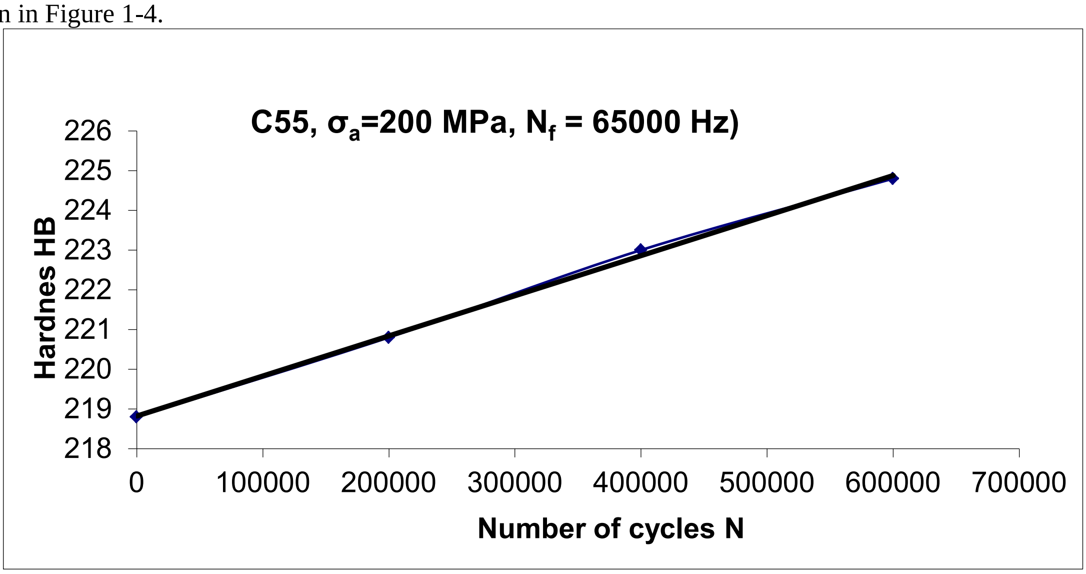

Fig. 1 Development of surface hardness of C55 steel during cyclic loading

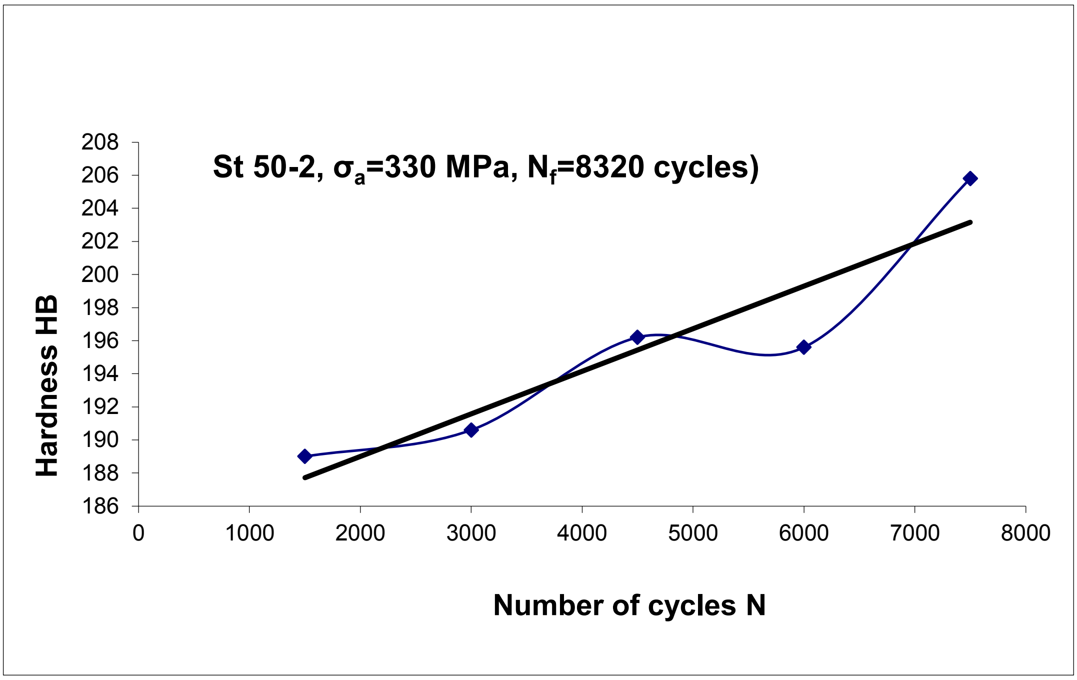

Fig. 2 Development of surface hardness of St 50-2 during cyclic loading

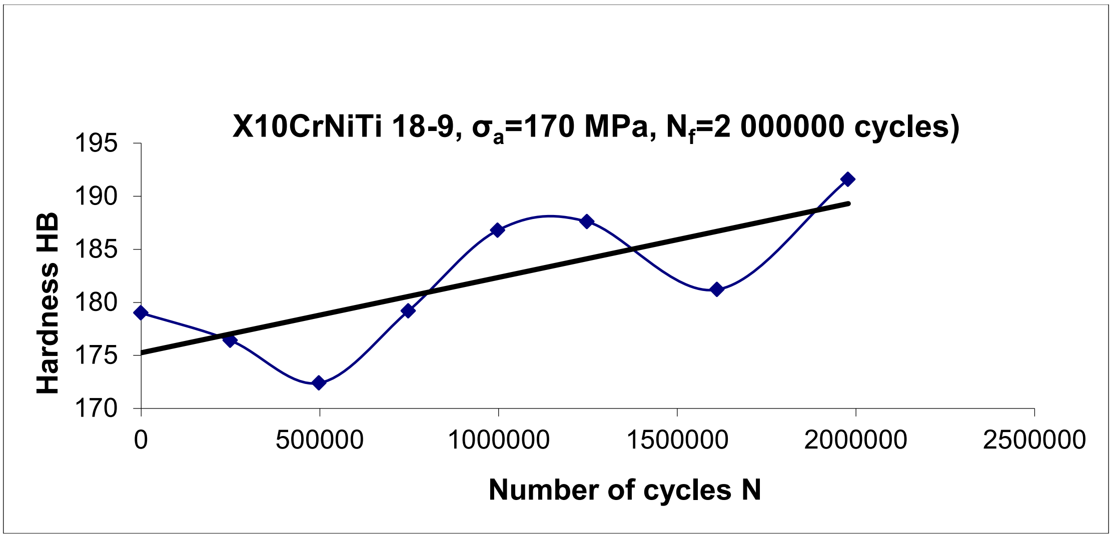

Fig. 3 Development of surface hardness of X10CrNiTi189 steel during cyclic loading

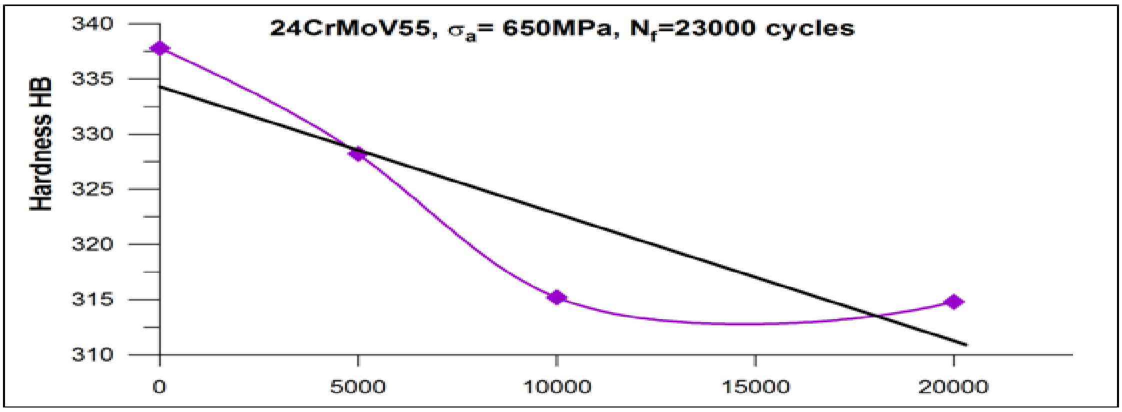

Fig. 4 Development of surface hardness of 24CrMoV55 steel during cyclic loading

V. CONCLUSIONS

From the review of non-destructive methods of measuring the properties of materials, the method of hardness measurement of the surface layer of the material was used. During the loading by the harmonic cycles of force (R = -1) th ehardness of the surface layer was measured by the HB1/30/10 method at specified intervals.
From the results obtained for 4 types of steel, several preliminary conclusions could be made:

- The hardness of the surface layer of the material varies with an increasing number of stress cycles and it can be shown that in some cases it could be an indicator of fatigue damage even though it was not possible to obtain an exact model describing this behavior of individual steels
- the trend in developement of hardness of the surface layer during cyclic loading are influenced by cyclic consolidation processes (cyclic softening or cyclic hardening) of the materials (C55 steel is a cyclically hardening material and the hardness of its surface layer is also increased, while 24CrMoV55 is cyclically softened and the hardness of its surface layer decreases during cyclic loading)
- the trend ofchange of hardness at the surface layer of the monitored steels depends also on the height of the individual stress amplitude levels of cyclic loading
- it is necessary to continue in experimental work for to obtain more experimental results for different materials [6-8] and different levels of cyclic loading for a deeper understanding of this phenomenon.

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