APPLICATION OF ELECTRO-PLASTICITY EFFECT AND SHEAROGRAPHY METHOD FOR NON-DESTRUCTIVE DETERMINATION OF RESIDUAL STRESSES

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The proposed technique introduces an innovative approach for the non-destructive determination of residual stresses by utilizing high-density current pulses (HDCP) along with the shearography method. During the testing of known stress state samples, graphs showing the dependence of $\partial w/\partial x$ on the stress state were acquired. Using this data as a foundation, algorithms were developed to determine residual stresses in elements of structures.

Keywords: residual stresses, high-density current pulses, electroplasticity effect, laser interferometry, shearography, interferometer

Ensuring high-quality manufacturing of structures is one of the most important scientific, technical, and production challenges in leading sectors of modern industry, the significance of which is growing increasingly as structures become more complex. The manufacturing of structures is typically accompanied by the appearance of residual stresses, which in certain cases can reduce their operational efficiency.

Relaxation methods are among the most common approaches for determination of residual stresses. They are based on measuring deformations of structural elements that occur due to the relaxation of stresses after their cutting or the creation of notches, and calculating the stress state using material mechanical properties such as the modulus of elasticity and Poisson's ratio. The hole drilling method has gained the most widespread use for residual stress measurement. However, despite its fairly extensive application, it remains destructive, which imposes certain limitations on its use. Therefore, the determination of residual stresses is often performed on separate mock-ups of elements from actual structures.

The paper proposes replacing the hole-drilling process for stress relaxation, which compromises the integrity of the surface of structures, with a non-destructive method of local stress relief using high-density current pulses. This approach aims to combine the benefits of mechanical relaxation methods with the possibility of non-destructive study of the stressed state of structural elements [1-2]. The proposed method relies on the electroplasticity effect, which occurs when introducing HDCP into the material under investigation, leading to stress relaxation in the local zone. Electroplasticity [3] is the phenomenon where a material undergoing deformation displays a drop in flow stress whenever subjected to an electrical pulse. The process involves using an electrode system and a power source capable of providing a current density ranging from 10^7 - 10^{11} A/m^2. The power source offers extensive possibilities for adjusting the main electrical parameters, allowing for the desired form of current pulses. To assess the influence of the electrode system parameters on stress relaxation, the researchers developed and manufactured a mechanical device capable of loading test samples. A beam with equal bending resistance is employed as the test sample for the experiments.

Laser interferometry methods are known for their application in contactless displacement measurements around holes, aiming to replace strain gauges and acquire more input data for stress value calculations [4]. In the study, the potential use of the shearography method [5] was explored to register deformations around the point of introduction of HDCP. Unlike speckle interferometry, this method offers several advantages, including equipment mobility and compactness, significantly reduced requirements for the laser illumination source and vibration protection. Figure 1 presents the view of the shearography interferometer and a test sample made from aluminum alloy.

Fig. 1. Shearographic measuring system and test specimen of aluminum alloy.

The methodology for stress determination using the *dw/dx* data obtained through shearography after introducing HDCP into the stressed material is as follows. The application of a current pulse leads to local deformation within the observation area captured by the shearographic interferometer. Figure 2 presents a typical shearographic pattern, which exhibits two characteristic zones positioned at a shear displacement distance. The green color illustrates the distribution of *dw/dx* values along a horizontal section at a certain distance from the center of the current pulse introduction. Negative derivative values are obtained around one zone, while the other shows positive values. It has been experimentally determined that the higher the stress in the material, the greater the difference between the maximum and minimum distribution of the derivative along this section. By establishing the relationship between the deformation amplitude *dw/dx* and the stressed state, it becomes possible to calculate stress values at the point of current pulse introduction.

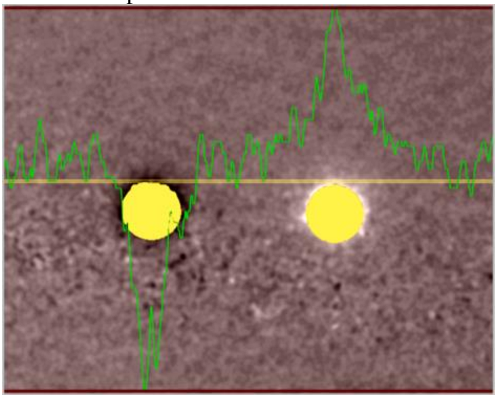

Fig. 2. Diagram of the derivative distribution along the selected cross-section obtained experimentally.

To establish the stress-amplitude *dw/dx* relationship, calibration of both the optical and electrical systems was carried out using a test sample made of the AMg5 alloy. For this purpose, an HDCP was introduced into a specific region of the test sample with a known stressed state. Subsequently, the shearographic interferometer recorded values and calculated the *dw/dx* amplitude. Figure 3 illustrates the experimentally obtained *dw/dx* dependence on stresses in an 8mm-thick beam with uniform bending resistance. This relationship shows linearity with a coefficient of determination R^2 = 0.9, indicating a good accuracy of approximation. Therefore, this relationship can be utilized as a calibration reference.

The dimensions of the electrode's imprint on the surface of the investigated object after the current pulse introduction has a diameter of less than 0.5 *mm* and a depth of up to 50 μm. These dimensions enable us to consider this method non-destructive.

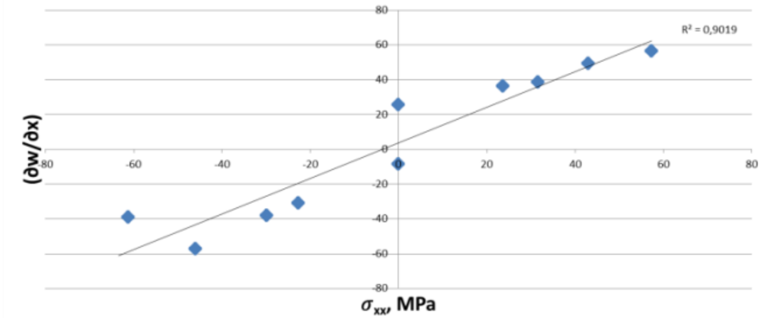

Fig. 3. Dependence of the displacement derivative on the specified stresses in the 8 mm thick beam with equal bending resistance. Material – AMg5 alloy

Thus, the study conducted experimental investigations on samples made of the AMg5 aluminum alloy, which allowed obtaining dependencies of deformations measured by the shearography interferometer in the stress relaxation zone. These dependencies were derived from uniaxial stressed states for defined parameters of the electrode system. Based on this data, an approach has been proposed that will enable the estimation of residual stresses.

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