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DEVELOPMENT OF METAL MAGNETIC MEMORY METHOD FOR DETERMINING RESIDUAL STRESSES IN THE PRODUCTION OF WELDED PIPES

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Annotation. *The article proposes the use of the metal magnetic memory method for the purpose of detecting and measuring residual stresses in welded seams and heat-affected zones of longitudinal welded pipes. The experimental study was divided into the following stages: measurement of residual stresses in the weld section of a pipe that has not undergone heat treatment; measurement of residual stresses in the weld section of the heat-treated pipe; analysis of the results obtained. The measurements were carried out in the cross section of the samples, which made it possible to obtain data on the residual stresses contained in the weld, the near-weld zone and the base metal of the pipe.*

The study confirmed the feasibility of using the metal magnetic memory method to measure residual stresses in welded pipes for further development and modernization of the technological process for the production of longitudinal welded pipes.

Key words: *metal magnetic memory method, weld seam, heat-affected zone, residual stresses, pipe billet.*

Introduction.

Increasing the competitiveness of products is directly related to the introduction of progressive methods for obtaining new grades of pipe steels and technologies for their production, improving the internal structure of the metal as a result of removing internal stresses, as well as improving the properties of products obtained by welding.

Formation of high-quality geometry of large-diameter pipes ($D \leq 1420$ mm) according to the “sheet-tube” technological conversion [1] begins in the bending press, where the formed profile of the edge sections of the pipe billet should ensure smooth conjugation with the main perimeter of the pipe on the step-by-step press. It should be borne in mind that after removing the load, residual stresses are formed in the sheet blank, causing the sheet formed for welding to spring.

Formulation of the problem.

Residual stresses are associated with changes in the volume of the metal and structural transformations that occur in the atomic lattice, and persist over time in the absence of external forces. The main reason for their occurrence is the heterogeneity of the deformed state due to different changes in length (volume) in different zones of the body, which can be caused by the following factors: temperature gradient (thermal stresses); inhomogeneity of thermal expansion of various structural or structural components of the body (heterogeneous structures, bimetals, etc.); phase transformations (phase voltages); inhomogeneity of plastic deformation during molding (residual stress after welding).

Analysis of publications on the topic of research.

From scientific sources it is known [2] that in atomic lattices of metals, for various reasons, distortions can occur with violation of the correct arrangement of atoms, for example, dislocations. In this case, the dislocation can be considered as an extra plane wedged between two adjacent planes, and, as it were, expanding the atomic lattice in this place. The atoms located in the planes adjacent to the dislocation shift from their normal (equilibrium) position in the given lattice. The tendency of these atoms to an ordered arrangement also causes the appearance of internal interatomic stresses. The martensitic structure that appears in steel after quenching is characterized by a large number of dislocations, and also has an atomic lattice in which carbon atoms are located between iron atoms. All this leads to the expansion of the lattice, its distortion, and, consequently, causes internal interatomic stresses.

The main methods for determining residual stresses in metals are mechanical and X-ray.

Mechanical methods for measuring residual stresses are based on the principle of elastic unloading of metal when it is released from internal stresses by cutting. By measuring the deformations that occur during cutting, it is possible to calculate the residual stresses according to the formulas of the theory of elasticity.

X-ray methods for determining residual stresses make it possible to directly measure the strains of the crystal lattice when exposed to stresses without destroying the product. These methods are based on determining the distance between crystallographic planes by measuring the angle of reflection of the beam. With such scattering, the interference of the rays occurs, as a result of which only in certain directions the intensity of the rays increases, while in other directions it is weakened.

Analysis of the known methods for measuring stresses and strains in metals allows us to name their main disadvantages [3,4]:

- locality of control, high labor intensity and unsuitability for control of extended sections and surfaces of structures;
- the need for special preparation of the controlled metal surface (cleaning, magnetization, etc.);
- incomparability of depth and area of control and, as a rule, significant error of results;
- the complexity of determining the position of the control sensors in relation to the direction of action of the main stresses and strains;
- compulsory construction of calibration curves on pre-fabricated samples;
- large uncertainty to get into the stress concentration zone during control (or determine it);
- the ability to carry out measurements only in a thin surface layer of metal (less than 0.1 mm) or to determine the average stresses over the thickness;
- relatively low control efficiency.

The purpose of this study is to study the possibility of using the metal magnetic memory method to measure internal stresses in the weld section and the heat-affected zone of longitudinal welded pipes.

X-ray and other traditional methods for measuring internal stresses do not provide a sufficient and understandable picture of the internal state of the metal, therefore, this work proposes a method for measuring stresses MMM [5] (metal magnetic memory method), which is promising for electric pipe production, during the production of welded pipes.

Presentation of the main material.

The uniqueness of the magnetic memory method lies in the fact that it is based on the use of the intrinsic magnetic field of the metal under study, which arises in the zones of stable slip bands of a dislocation caused by the action of working loads. As a result of the interaction of the intrinsic magnetic field with the Earth's magnetic field in the stress concentration zone on the surface of the test object, a stray magnetic field gradient is formed, which is recorded by specialized magnetometers. The mechanism of the appearance of an intrinsic magnetic field on dislocation clusters is due to the pinning of domain walls, when these clusters become commensurate with the thickness of the domain walls. Under no circumstances with artificial magnetization in working structures such a source of information as the intrinsic magnetic field is impossible to obtain. Only in a small external field, such as the Earth's magnetic field, in loaded structures, when the deformation energy is much higher than the energy of the external magnetic field, such information is formed and can be obtained. In this case, the regions of anomalous changes in the magnetic field of leakage are determined, due to the inhomogeneity of the stress-strain state and the presence of zones of stress concentration in the metal. Under the action of working loads, the remanent magnetization and, accordingly, the magnetic field of leakage are redistributed and irreversibly change in the direction of action of the main stresses.

The metal magnetic memory method does not provide a direct quantitative assessment of the acting stresses (unlike, for example, strain gauges). However, it is devoid of the disadvantages indicated above, and allows one to distinguish the elastic deformation region from the plastic one, and allows one to determine the sliding areas of metal layers and the zones of fatigue crack initiation.

When carrying out work on the control of internal stresses, the TSC-1M-4 apparatus (stress concentration meter) was used. The general view of the TSC-1M-4 apparatus is shown in Fig. 1.

According to the principle of operation, the TSC-1M-4 apparatus is a specialized multichannel fluxgate magnetometer based on the phenomenon of electromagnetic induction, namely, the emergence of an EMF (electromotive force) in the measuring coil when the magnetic flux passing through its loop changes. A change in coil flux can be caused by the following factors:

- change in the magnitude or direction of the measured field in time;
- periodic change of position (rotation, oscillation) of the measuring coil in the measured field;
- a change in the magnetic resistance of the measuring coil, which is achieved by a periodic change in the magnetic permeability of the permalloy core (it is periodically magnetized until it is saturated with an auxiliary alternating excitation field).

The control is carried out using a scanning device consisting of a flux-gate transducer and a mechanism that allows, simultaneously with measuring the values of the magnetic field strength H_s, to measure the length of the controlled section [6]. The measuring device displays information about measurements both on the display of the device and through the built-in port on the screen, which makes it possible to determine the most dangerous voltage concentration zones directly on the spot.

The graphs generated by the device describe with the help of lines the nature of the placement and the magnitude of residual stresses in the metal under study. The H_s line is a curve that describes the strength of the magnetic field of the workpiece, and by itself does not carry a complete picture of the stress concentration zones. Therefore, an additional characteristic is introduced that more accurately depicts the stress concentration zones – the gradient of the magnetic field of the workpiece.

Fig. 1. General view of the TSC-1M-4 apparatus.

The intensity gradient characterizes the increase or decrease in intensity in an inhomogeneous magnetic field per unit distance. This concept is an essential addition to the usual (maximum) characteristic of the magnetic field strength. In the graphs, the gradient of the magnetic field strength is represented by the dH / dx curve.

The places where the stress concentration zones are observed are considered to be the extremes of the dH/dx graph curve. On the H_s axis, the values of the magnetic field strength of the workpiece under study are plotted. The Lx axis represents the measurement of the length of the transducer, which makes it possible to say exactly where the stresses are present. The values of the gradient of the magnetic field strength are plotted along the dH/dx axis, it is according to the values of the last two measurement scales that the stress concentration zones are determined.

Research results.

During the research work, several test measurements were carried out. In the first part of the study, the internal stresses of a pipe billet with diameters of 100 mm and a length of 150 mm were measured in the section of the welded seam that had not undergone heat treatment. We select 7 zones of stress concentration, of which we will select the 3 most dangerous zones, for comparison with thermally treated seams. The first coordinate is the scale – Lx, the second – dH/dx. These zones will be the peaks of the curves with coordinates $A_0(77;130)$, $B_0(66;55)$, $C_0(19;45)$. The graph of internal stresses in the section of the welded seam of a pipe that has not passed heat treatment is shown in Figure 2.

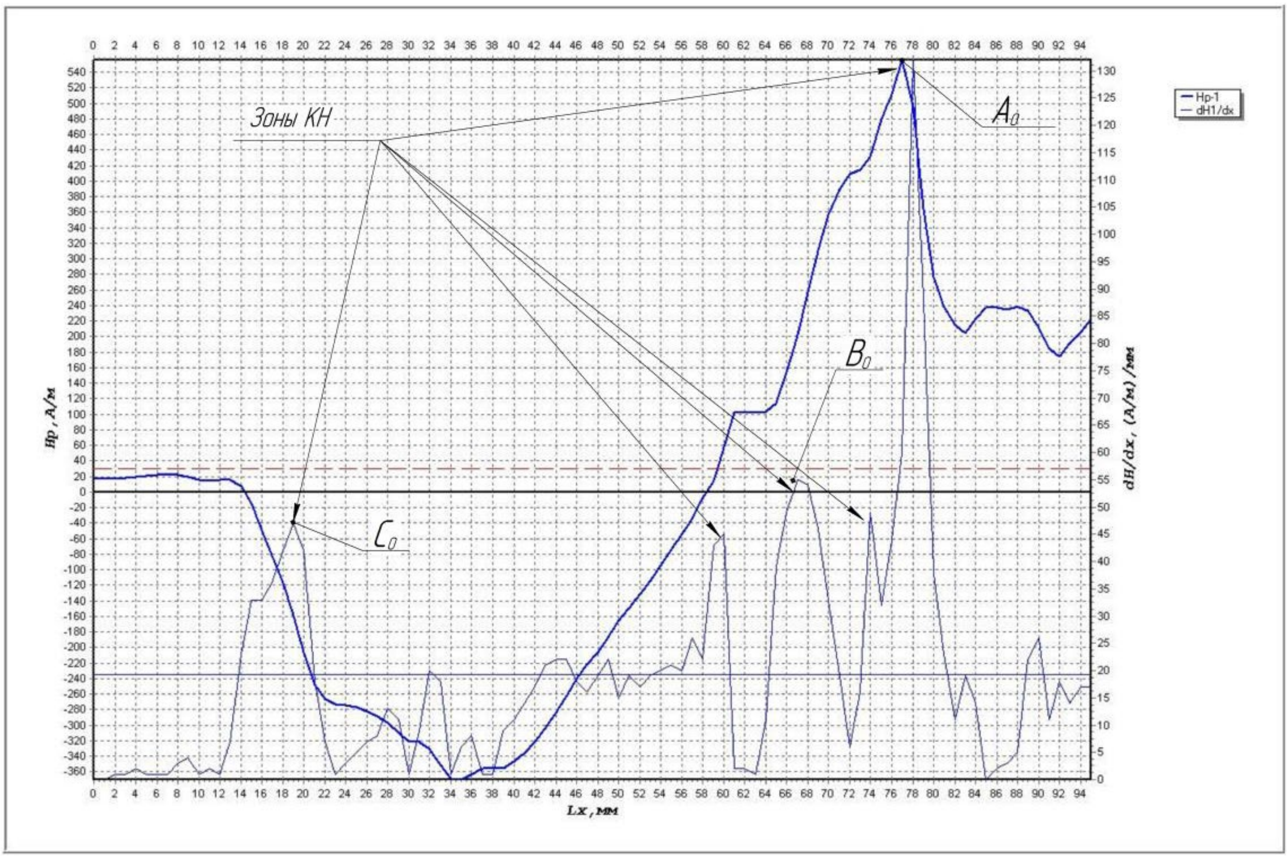

Fig. 2. Internal stresses in the section of the welded seam of a pipe that has not undergone heat treatment

In the second part of the study, the internal stresses of the pipe billet, presented in the first part of the experiment, were measured with heat treatment of the welded seam in laboratory conditions. Heat treatment is intended in this case to relieve residual stresses that have arisen in the welded seam and the heat-affected zone as a result of welding the formed sheet blank. The graph of internal stresses after heat treatment of the weld is shown in Figure 3.

Figure 3 shows 5 zones of stress concentration. From the presented zones, as before, we will select 3 points for comparison. They will be $A_1(78;84)$, $B_1(58;64)$, $C_1(6;44)$. From the graphs obtained, conclusions can be drawn about the difference in the magnitude of the peaks of the stress concentration zones. During the test, it is worth noting that the basic heat treatment gives the effect of removing internal stresses (as can be seen from the comparison of the extrema of the graphs, which are shown in Figures 2 and 3), as well as from the coordinates of the vertices characterizing the stress concentration zones. Table 1 presents the numerical results of the experiment.

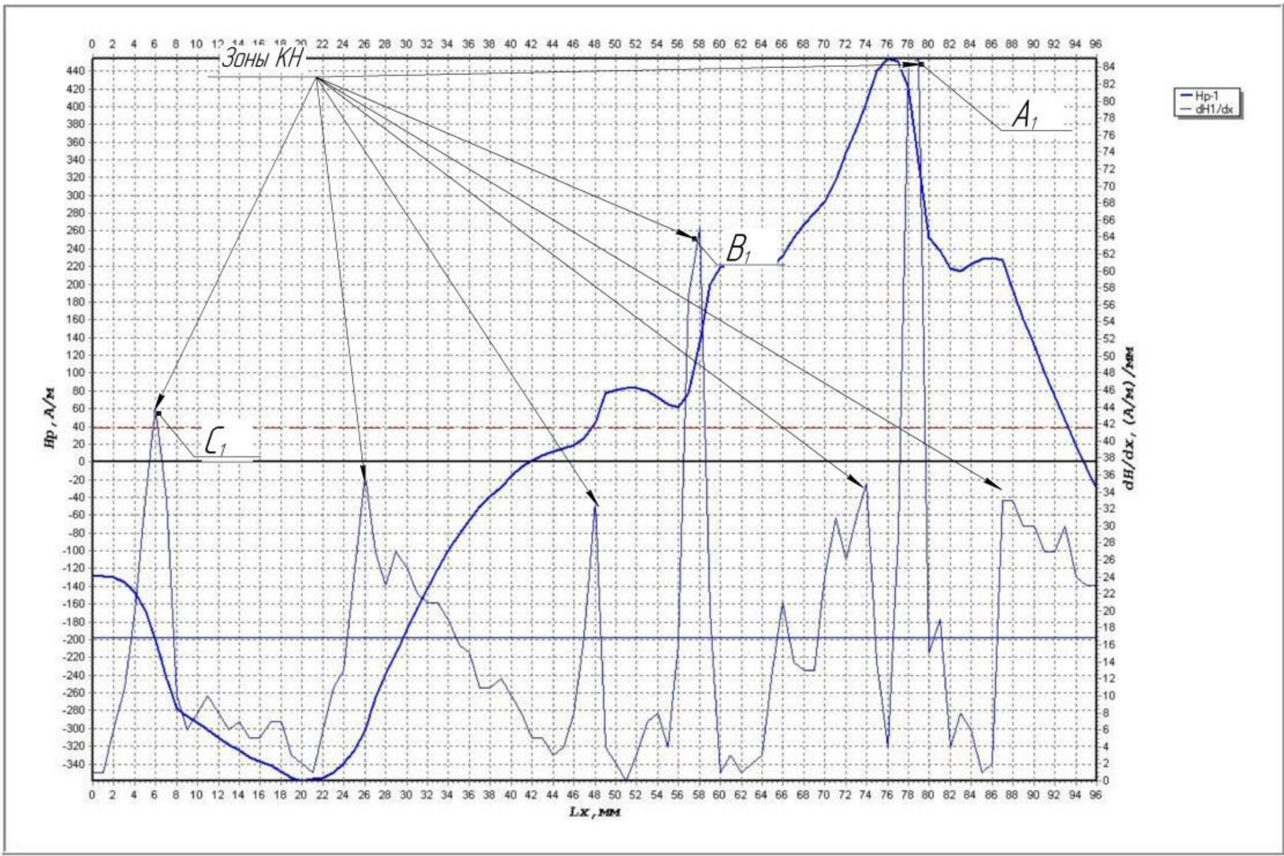

Fig. 3. Stress graph in the section of the welded seam of a thermally treated pipe

Table 1.

Results of the experiment.

dH/dx value for the first sample (without heat treatment)	dH/dx value for the second sample (with heat treatment)	Residual stress relief by heat treatment, %	Average stress relief for the sample
130	84	35,38%	7,08%
55	64	-16,36%	
45	44	2,22%	

As can be seen from the values in the table, the heat treatment in laboratory conditions was carried out with some violations of the technological process and did not lead to the necessary indicators for the removal of residual stresses, the general level of stress relief was 7.08%. Of interest is the fact that the values of residual stresses at point B_1 after heat treatment increased in comparison with the values of B_0. This fact can be explained by the redistribution of stresses between the sections of points A and B due to heat treatment of the sample.

Conclusions.

The results obtained during the experiment clearly prove the feasibility of using the metal magnetic memory method to measure residual stresses in welded seams and near-weld zones of pipes for further development and modernization of the technological process for the production of welded pipes.

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