RESULTS OF STEEL 20 SPECIMENS TENSILE TESTING USING THE METAL MAGNETIC MEMORY AND ACOUSTIC EMISSION METHODS

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Abstract.
The results of the steel specimens' tensile tests, which were performed simultaneously with metal magnetic memory method and acoustic emission diagnostic parameters registration, are adduced in the paper. There are tensile test diagrams $\sigma$-$\varepsilon$ describing the mechanical properties of the specimens (yield stress $\sigma_y$ and tensile strength $\sigma_t$), which are compared with the metal magnetic memory method and acoustic emission parameters. As a result of performed tests, the identical energy dependence of magnetic and acoustic parameters with the mechanical properties of metal (yield stress and tensile strength) was established. It was discovered that there is possibility of complementarity metal magnetic memory method and acoustic emission when used in combination in practice.

It is known that during standard tensile testing of steel specimens force (tensile strength $\sigma_{0.2}$ and ultimate strength $\sigma_t$) and strain (relative elongation $\delta$ and contraction $\psi$) material characteristics are obtained, which are conditional. They are conditional because the prerequisites are: a certain shape of the specimen and a certain test procedure.

Furthermore, such specimen testing results in obtaining of stresses ($\sigma_{0.2}$, $\sigma_t$), which are not internal stresses occurring on the specimen during tensile strain; they represent only a conditional stress equivalent – an external specific force applied to a specifically shaped specimen.

One more important characteristic of the metal’s mechanical properties is proportional limit – $\sigma_{p.l.}$ (or elastic limit). This important, but conditionally specified characteristic has a clear physical interpretation: near the conditional conventional proportional limit on the "stress-strain" curve there is a point, characterized by the fact that the increment of elastic and plastic components of longitudinal strain at low load variation are equal in it – the derivatives of elastic and plastic strain components by stress are equal.

During the normal standard tensile testing of a specimen the test machine recording device produces a “stress-strain” diagram ($\sigma$-$\varepsilon$) showing the values of $\sigma_{0.2}$ and $\sigma_t$. It is impossible to determine the value of proportional limit $\sigma_{p.l.}$ on this diagram.

Let us consider the capabilities of the metal magnetic memory (MMM) method and acoustic emission (AE) during determination of the above mechanical characteristics on the example of tensile testing of individual steel specimens.

Figure 1 shows the shape and dimensions of steel 20 specimens, on which comparative studies were carried out.
Figure 1 Shape and dimensions of the specimen: B – upper clamp; H – lower clamp; I, II, III, IV – numbers of three-component sensors \((H_I, H_J, H_L)\); + – locations of MMM sensors mounting; o – locations of AE sensors mounting; A – A – specimen section.

Tensile testing of specimens was carried out simultaneously with measurement of the specimen’s self-magnetic field using several three-component sensors mounted along the work surface of the specimen near its surface at an equal distance between sensor centers (Figure 1).

To record and process acoustic impulses the acoustic emission system SDS was used. The system included a system unit and personal computer with software (“Maestro” software).

MMM sensors were connected to a specialized TSC-5M-32 type magnetometer with a recording device and a memory unit. AE sensors were mounted between the test machine clamps and the specimen’s work surface (see Figure 1) and connected to the recording device. Tensile load was applied to the specimen with pre-specified strain rate up to its failure. The test machine recording device plotted a load-elongation diagram “P-Δl” with its further conversion using the known algorithms into the stress-strain diagram “σ-ε”.

Figure 2 shows the stress-strain diagram “σ-ε” plotted based on the results of one of steel 20 specimens tensile testing. The same Figure 2 shows the graph of the resulting magnetic field \(|ΔH|\) variation depending on strain \(ε\).

In this case variation of the resulting magnetic field \(|ΔH|\), which takes into account the relative variation of the specimen’s state as compared to the initial state, was calculated by the results of measurement with a three-component sensor in the closes point to the specimen rupture place using the algorithm: \(|ΔH| = \sqrt{H_x^2 + H_y^2 + H_z^2}\). Then, using the graph in Figure 2, a comparison was carried out and \(|ΔH|\) values were determined that correspond to yield strength \(|ΔH|_y\), ultimate strength \(|ΔH|_t\) and the limit stress value in the specimen’s neck at the moment of its failure \(|ΔH|_lim\).

Using the obtained during specimen testing \(|ΔH|\) values corresponding to mechanical parameters \(σ_y, σ_t, σ_{lim}\), the limit value of the magnetic index \(m_{lim}\) was determined using the ratio:
where $\sigma_{\text{lim}}$ is a true value of stresses in the maximum specimen contraction zone (in the “neck”).

By inserting the numerical values of magnetic and mechanical parameters from the specimen test results (Figure 2) into ratios (1) and (2), we obtain:

$$m_{\text{lim}} = \frac{120\text{A/m}}{80\text{A/m}} = 1.5 \approx \left(\frac{330\text{MPa}}{270\text{MPa}}\right)^2 = (1.22)^2 \approx 1.49.$$  \hspace{1cm} (1)

$$m_{\text{lim}} = \frac{175\text{A/m}}{120\text{A/m}} = 1.46, \; \sigma_{\text{lim}} = 1.46 \times \sigma_t = 1.46 \times 330 \approx 482 \text{MPa}.$$ \hspace{1cm} (2)

Numerical values of ratios (1) and (2), obtained at different levels of stresses and strains, turned out to be approximately equal with a minor error:

$$\frac{1.49 - 1.46}{1.49} \times 100\% \approx 2\%.$$  

It is suggested to use energy ratios (1) and (2) obtained during the specimen testing in determination of the limit value $m_{\text{lim}}$ directly on the equipment made of the same material as the specimen.

The energy ratio (1) obtained by the acoustic emission parameters turned out to be approximately equal to the energy ratio obtained by the metal magnetic memory parameters. The obtained result may be explained as follows. Consideration of the ratio (1) based on the results of the specimen tensile testing by the MMM method took into account the values of the magnetic field and its variations recorded at the closest measurement point to the specimen rupture place, i.e. to the local place of non-uniform strain. Therefore, for an objective comparison of the MMM method and the AE method energy parameters, the results of AE parameters measurements (total pulse count - $\sum N$ and total energy - $\sum E$) exactly in the area of the specimen non-uniform strain (“neck” zone) were considered.

Conclusions

1. The obtained results of specimens tensile testing using the MMM and AE methods revealed the same energy relation of the used parameters, magnetic and acoustic, respectively, with mechanical characteristics of the metal $\sigma_t$ and $\sigma_y$.

2. Tensile testing of specimens for the first time resulted in obtaining the energy ratio between the AE parameters (total pulse count - $\sum N$ and total energy - $\sum E$) and mechanical characteristics of the metal $\sigma_t$ and $\sigma_y$. Practical application of this ratio will allow to perform quantitative assessment of the metal’s limiting state during the diagnostics of actual equipment.

3. Compared to the AE method, the MMM method demonstrated an advantage in localization of stress concentration zone (the potential “neck” zone) on the specimen at the stage before the yield point ($-0.5$ to $0.6\sigma_t$).
4. Based on the results of AE impulses recording, at the stage of specimen strain until the yield point it is difficult to distinguish between signals associated with the specimen clamping in the test machine from the signals on the specimen’s work surface.

5. The possibility of the MMM and AE methods to mutually complement each other during their combined application in practice was revealed. The MMM method may be applied at an earlier stage (at the level of $-0.5$ to $0.6\sigma$) to detect the maximum stress and strain concentration zone, and then AE sensors may be installed in this zone with accuracy of up to 1 mm to conduct monitoring.