MECHANICAL MEASUREMENTS

STANDARDIZATION OF THE METROLOGICAL PARAMETERS OF MEASURING INSTRUMENTS USED DURING TENSILE TESTS FOR DETERMINING YIELD STRENGTH

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The most important method of determining the strength of materials is by tensile testing. However, investigations conducted in the USSR and abroad have shown that the measurement accuracy during tests is inadequate. The measurement errors often exceed the allowable variation in the material parameters and thus make it difficult to choose the optimum technological process. Such a situation leads to extremely undesirable consequences of a technical and economical nature.

The types of parameters which are measured during tensile tests are laid down in the relevant standards and instruction manuals. The most important parameter is the yield strength which is also the most difficult to determine since it is functionally dependent on two variables—load and deformation.

Unfortunately, at present, metrological parameters have been standardized only for load measuring instruments and hence it is not possible to ensure uniformity or to compare test results within the country. In a majority of cases the deformation measuring instruments are not serviced by metrological staff and this leads to obvious difficulties.

A general equation for the error in measuring yield strength is derived below. This equation makes it possible to determine standards for metrological parameters of deformation measuring instruments; to make a rational selection of numerical values for deformation measuring instruments if the corresponding values for the load measuring instruments are given; to evaluate the error in measured results knowing the metrological parameters for both the load and deformation measuring instruments; and also to establish the functional effect on the measured value of other parameters (not measured) which play a role during the tensile test.

In order to determine the yield strength the load and deformation of the test specimen are measured and then used for plotting the tensile test diagram $\sigma(e)$ for the material. The assumed value for permanent strain $e_0$ is set off on the deformation axis (Fig. 1). A straight line $f_0(e)$ is drawn through the selected point parallel to the linear portion of the diagram to determine the point of intersection $A$. This point gives the required value for yield strength $\sigma_0$. Thus, the yield strength $\sigma_0$ is a function of $\sigma$ and $e$.

Let us denote

$$\frac{\Delta \sigma(e)}{\Delta e} = \alpha E, \quad \Delta e \to 0$$

where $E$ is the normal modulus of elasticity of the material.

From Fig. 1

$$f_0(e) = (e - e_0) E.$$  

(2)

Since there are errors in the load and deformation measuring instruments, the function $f_0(e)$ is determined with an error $\Delta f_0(e)$ which is given by the full differential of Eq. (2). Thus, the actual value of the function is $f_0(e) = f_0(e) + \Delta f_0(e)$ and the point of intersection of $f_0(e)$ with the tensile test diagram gives the value $\sigma_0' = \sigma_0 + \Delta \sigma_0$.


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The error in measuring the modulus $E$ can be expressed in terms of the errors in load and deformation because $E = \sigma_E / \varepsilon_E$ ($\sigma_E$ and $\varepsilon_E$ are the values of load and deformation in the elastic zone of the tensile test diagram). With reference to Figs. 1, 2 we have $\Delta f_0(\varepsilon) = BC; \Delta \varepsilon = AD; \Delta \sigma = LN$. On the basis of geometrical relationships and considering Eqs. (1), (2) the error in measuring yield strength can be expressed in the following way:

$$\Delta \sigma_0 = \frac{\alpha}{1 - \alpha} E \left( -\Delta \varepsilon + \Delta \sigma_0 + \Delta \sigma_E \frac{e - e_0}{e_E} \right)$$

$$+ \frac{1}{1 - \alpha} \frac{\alpha}{1 - \alpha} \Delta \varepsilon \frac{e - e_0}{e_E},$$

where $\Delta \sigma$ and $\Delta \varepsilon$ are the errors in measuring load and deformation; $\Delta \sigma_E$ and $\Delta \sigma_E$ are the errors in measuring load and deformation within the elastic zone of the tensile test diagram.

Considering that $\sigma_0 = (e - e_0)E$, the error $\Delta \sigma_0$ expressed in relative units is given by

$$\delta \sigma_0 = \frac{\alpha}{1 - \alpha} \left( -c \delta \varepsilon + (e - 1) \delta \sigma_0 + \delta \sigma_E \right) + \frac{1}{1 - \alpha} \delta \sigma - \frac{\alpha}{1 - \alpha} \delta \sigma_E,$$

where $c = e/(e - e_0)$.

From Eq. (4) it follows that the tensile test diagram is fully defined by the coefficients $c$ and $\alpha$, and that the error in measuring the yield strength is dependent not only on the errors in the load and deformation measuring instruments but also on the physical characteristics of the specimen itself. Therefore, while measuring $\sigma_0$ we can only consider the error in the measuring process within a system comprising of the test specimen and the measuring instruments. If it is assumed that there are no errors in the graphical or mechanical plotting of the tensile test diagram (according to the method given above), then the errors due to the load and deformation measuring instruments only are considered in Eq. (4) and $\delta \varepsilon_0 = 0$.

In accordance with Eq. (4) and the given metrological parameters for the load measuring instrument it is possible to develop a rational expression and numerical values for standardizing the main error (metrological parameters) of the deformation measuring instrument. The results of measurements by the load and deformation measuring instruments figure twice in Eq. (4); within the linear zone of the diagram ($\sigma_E$, $\varepsilon_E$) and in the plastic deformation zone ($\sigma$, $\varepsilon$) corresponding to $\varepsilon_0$. The total error $\delta \sigma_0$ depends considerably on the nature of distribution of error over the entire measuring range

$$\delta \sigma_0 = \varphi [\delta \sigma(\varepsilon); \delta \sigma(\sigma)].$$

The load and deformation measuring instruments are of the linear type and therefore, according to [1], the error should preferably be expressed as a multinomial

$$\delta x = a_0 \frac{x}{m} + a_1 + a_2 (1 - m),$$

where $a_0$ is the zero drift; $a_1$ is the difference in angle of inclination between the real transformation function and the calibration function; $a_2$ is the coefficient of non-linearity; $m = x/x_r$ is the ratio between the measured dimension and the measuring range.

According to the standards on testing methods, the load and deformation measuring instruments are set (zero-adjustment) just before starting tests. Since the measuring cycle does not exceed 10 min it is possible to neglect any zero-drift.

It can be easily proved using Eq. (4) that if $a_1 = a_2$, then the error due to deviation in the coefficient $a_1$ is always more than the error due to non-linearity in the transformation function $a_2$. 

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