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DETERMINATION OF YIELD POINT OF STRUCTURAL MATERIALS WITH USING THE METRIC ENTROPY

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Abstract

The yield point is one of the basic characteristics of construction materials, which are used in the design engineering calculations. The methods used to determine the yield point is based on the interpretation of the geometric shape of the curve uniaxial tension. This shape is specific for different construction materials and depends among others to the conditions carrying trials. Specific guidelines for determining the yield point were included in the standards specification. The conventionality of procedure concerns especially materials, which, in their deformation characteristic do not have a distinct top of knee. The authors propose an alternative method based on the use of the concept of the metric entropy by Kolmogorov-Sinai. The metric entropy by Kolmogorov-Sinai is used to study the phenomena about a dynamic character. Therefore, this method requires the recording of more number of measuring points: from a few hundred to a dozen thousand, depending on the type of research of constructional materials. A dynamic character of measurement data results from their scatter, which consists of local, non-linear disturbances occurring during deformation of the material and the noise, associated from the action of acquisition path. The aim of the study is to present a more objective method of determining the yield point structural materials, which do not require the use of conventional procedures. The paper presents the results determining of this constant material on the basis of data records monoaxially stretching of tests for metals used in shipbuilding.

Keywords: *yield point, construction materials, metric entropy by Kolmogorov-Sinai*

1. Introduction

The yield point is one of fundamental properties of constructing materials, which are basis for engineering calculations. For an ideal elastic-plastic body the yield point is unequivocal. However, real constructing materials can have non-linear elastic characteristics or their elastic characteristics can be devoid of a plateau. There are also materials, which have a transition effect on the elastic-plastic boundary. Methods of the yield point determination are shown in Fig. 1-3. These methods are based on the shape of the monoaxial tension curve. They are dependent on the kind of the material and conditions of material testing. Thus, they are subjective. The detailed recommendations of determination of the yield point are described in the norm [7].

The aim of this work to investigate more reliable method of determination of the yield point of constructing materials; it does not require arbitrary procedures. This alternative method is based on the Kolmogorov-Sinai metric entropy that can be applied in studies of dynamic phenomena [5, 8]. Monoaxial tension test data is treated as a set, which has inner dynamics. Dynamical character of measured data is a consequence of their scattering. This scattering consists of local non-linear perturbations, which occur during deformation of the material and noise from the experiment. The proposed method requires acquisition of larger number of points for a single test, i.e., from a few hundred to several thousand points, depending on the kind of studied constructing material.

2. Methods of carrying out the tests uniaxial stretching of materials

The methods of testing the uniaxial stretching of the construction materials by means of older testing machines were carried out by steering in a stroke loading the specimen. The weight of the load and the total obtained strains were put down in a form of a table that included a dozen or a few dozen-measurement points.

On the basis of the table, a suitable graph was made. Another variant of this sort of a test takes into account monitoring of dislocation or deformation obtained during the test. An application of the mechanisms allowing drawing the graphs up on a sheet of paper in a continuous way, without stopping the test to read the results, was a significant improvement. Carrying out the test on the contemporary machines consists in registering the values: the force of loading the specimen, displacement of the machine's traverse or strains measured with a help of an extensometer. Registering of the results takes place regularly. During a standard test of construction materials stretching, results can be registered for a few dozen thousands measurement points.

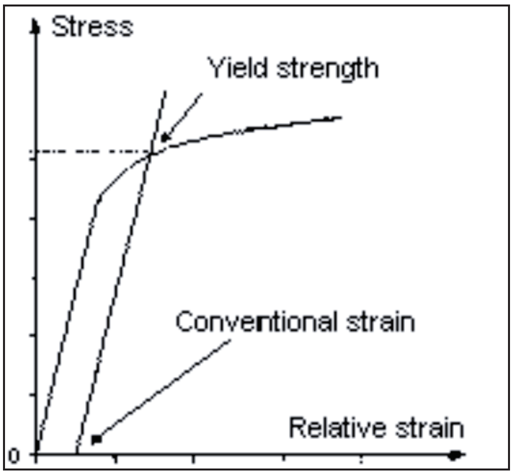

Fig. 1. Determining the conventional elastic stress for a material of no clear boundary between resilience and plasticity on the basis of the convention strain

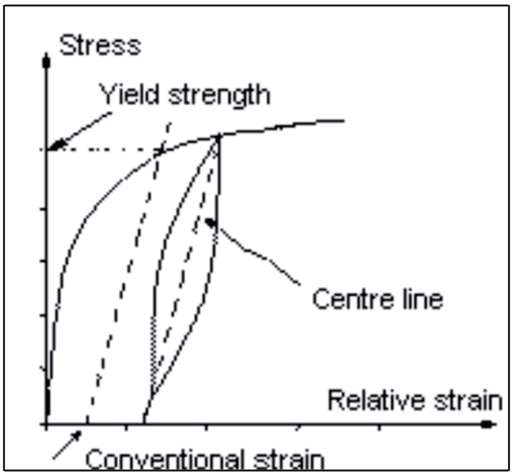

Fig. 2. Determining the yield strength of a non-linearly elastic material on the basis of the conventional strain referring parallel to the line of the middle line of a hysteresis loop, as a substitute linearly elastics characteristic

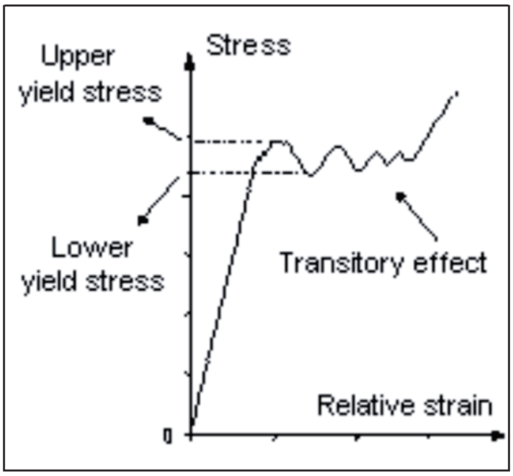

Fig. 3. Determining the yield strength of an elastic – plastic material with a transitional effect

3. Peculiarity of a measurement section of contemporary testing machines

The results of a test on mechanic features of certain materials depend on the quality of the measurement mechanisms, testing machine and the type of a specimen [1]. The quality of the measurement mechanisms is defined by the resolution and linearity of the mechanisms used to measure forces, displacements and strains. The quality of a loading mechanism, which usually is a tester with hydraulic drive, depends on the construction and workmanship of the hydraulic elements and the steering mechanisms that works usually in a loop system of feedback connections, where the starting steering signal at this very moment depends on the behaviour of the specimen that is being tested. The signal is defined as a difference between already programmed signal and a signal measured on a specimen.

The most important factor that influences the precision of a test concerns the type of a specimen that generates measurement distortion, depending on the starting point state of a specimen's material and the conditions of its fixing. Anisotropy and distribution of stresses within the material, the structure and material's crystallographic defects distort the homogeneity of the stresses' distribution and strains in the specimen's measurement field. They lead to the development of local fields of plastic strains also when treated with small forces, which do not exceed the elastic limit. Resolution, in other words, the precision of the measurement, is defined on the basis of the noise measurement. Other factors that influence the test's results are related to one another in a system machine-specimen that is controlled in a loop of feedback. The behaviour of this system depends on hydraulic system's quality and efficiency as well as the characteristics of a specimen being tested. Parameters of the feedback between the specimen and the machine must be regulated according to the specimen's predicted characteristics. Any distortions in the system machine-specimen are visible especially when the characteristic of a certain material changes, i.e. during the transition from elastics into plastic range, when transition into plastic strains occurs and rigidity of the measured system undergoes a sudden decrease. Damage of the specimen initiates a local process, which has got an effective impact on the dynamic characteristic of the whole system. During this transition, we can observe an increase of force error in relation to the applied force, but it is due to not only the measurement precision, but also the total effect of the measurement track's resolution, the efficiency of hydraulic system, the setting of the steering, and the degree of changes of the material's characteristics.

4. The structure of the measured data

Figure 5 shows a classic graph of a static test on stretching the 10GHMBA steel. This kind of a graph doesn't present the inside dynamics of the process of distorting materials. Chaotic arrangement of the measurement points are presented on the Fig. 5 by means of the consecutive enlargements of the fragments marked of the graph on the Fig. 4.

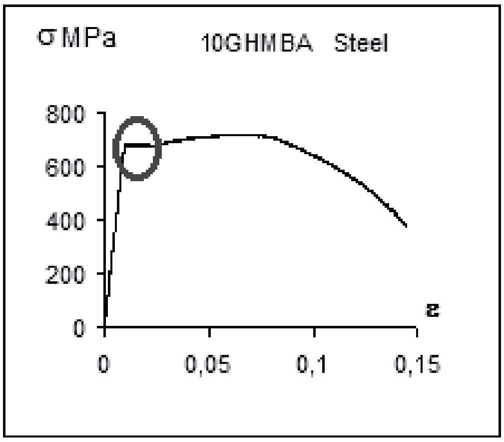

Fig. 4. The curve of the static stretching 10GHMBA steel

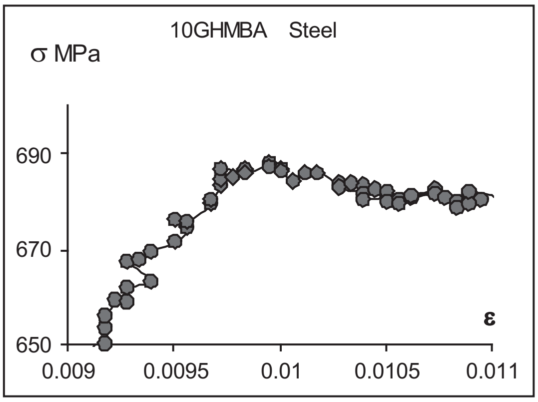

Fig. 5. The enlargement of the marked fragment of the curve from the Fig. 4

5. The method of determination metric entropy of measured data

A. Kolmogorov's and Y. Sinai's metric entropy used in that publication is a number that measures instability of system's dynamics, in other words, it is a method of numerical description of chaos. Entropy K - S for a discrete distribution of probability is expressed by a formula:

$$S = -\sum_{i=1}^{N} p_i \ln p_i, \tag{1}$$

where:

N – the number of intervals in which the data set of possible results was divided,

p_i – the probability of occurrence of results in i-interval (according to the definition of $p \ln p \equiv 0$, if $p=0$).

If intervals have equal probability $p_i = 1/N$ for all i, entropy has maximum value equal lnN.

Classic thermodynamic entropy links to an energy flow from great to small scale. The second principle of thermodynamics states that the entropy of an isolated system in irreversible processes tends to increase over time, approaching positive values. However, metric entropy Kolmogorov – Sinai links to energy flow of the opposite direction, that is dissipation from small to great scale. Energy dissipation is never a constant process. Entropy K - S as a dynamic notion, is "an entropy for a unit of time", so to say [4], and is non-negative, but may both grow and drop.

Figure 6 and 7 show graphically a calculation of K - S entropy for consecutive location of n- numerous measurement-set, with reference to experimental data.

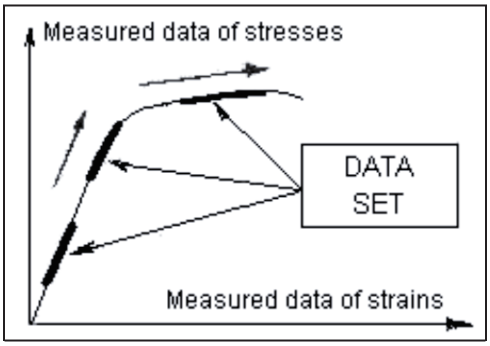

Fig. 6. Demonstration of data set's dislocation in reference to stresses or strains

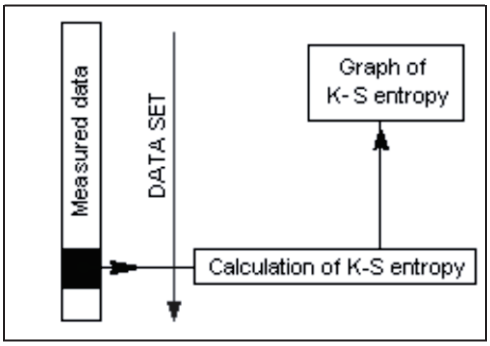

Fig. 7. Block diagram for the K-S metric entropy calculation

6. Determination of the yield point based on the Kolmogorov – Sinai metric entropy

Calculation of entropy is alternatively carried out on the basis of measured data of stresses or strains. As a result, the graph of K-S entropy in a function of measured points is related to a tension curve, denoted also in a function of measured points. The yield point is treated as a "critical point" that separates elasticity and plasticity as the phases of stretching the materials characterized by different inner dynamics. Decline of K – S entropy's values at the yield point, is a result of different physical relations of functions that are characteristic of the elastic and plastic phases [2], [3].The graph of entropy and its minimum is determined by means of a specially for that purpose created computer program. Before the beginning of any calculation, there must be established a quantity of n- elements of a data set, divided into N intervals. Final values of n and N are determined heuristically. Proper selection of n and N is responsible for clarity of graphs and occurrence of a definite local minimum of K-S entropy at the yield point of material. For the determination of the yield point was used the authorial computer program.

7. Results of materials testing

Chemical constitution of testing metals:

- Alloy PA47 (AlZn5Mg1) Aluminium – 94%, Zinck – 5%, Magnesium – 1%,
- Brass M058 (CuZn40Pb2) Copper – 58%, Zinc – 40%, Lead – 2%,
- SAW-1 (00H21AN16G5M4Nb) – to 0.06% Carbon, Chromium – 24%, Nickel – 16%, Molybdenum – 4%, Niobium – 0.3%, Manganese – 5%,
- 10GHMBA Steel – 0.1%, Manganese 0.8%, to 0.35% Silicon, 1.2-1.4%, Chromium, to 0.4%,
- Molybdenum, to 0.03% Titan and Niobium, and rest Carbon.

Experiential conditions [6]:

- displacement of the machine's traverse control,
- speed of tension – 25 mm / 300 s,
- frequency sampling – 0.0024414 sec. for PA47, MO58 and 10GHMBA,
- frequency sampling – 0.01 sec. for SAW.

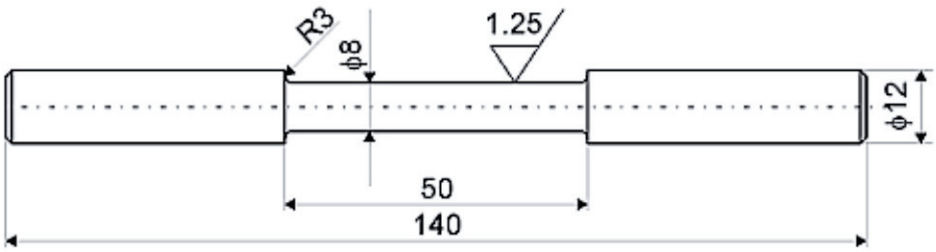

Fig. 8. Geometry of specimens

Tab. 1. Determined yield strength of testing specimens

	Yield point calculated	
kind of specimen material	based on the PN – EN norms [MPa]	based on the K – S entropy [MPa]
10GHMBA	682.55	681
PA47	338.34	331
MO58	362.78	236
SAW	281.43	313

Results of determination YP based on the K - S entropy ware carried out for a data sets of n = 100 measurement points, divided into N = 10 intervals.

Figure 9-12 show results of determining YP for tested materials.

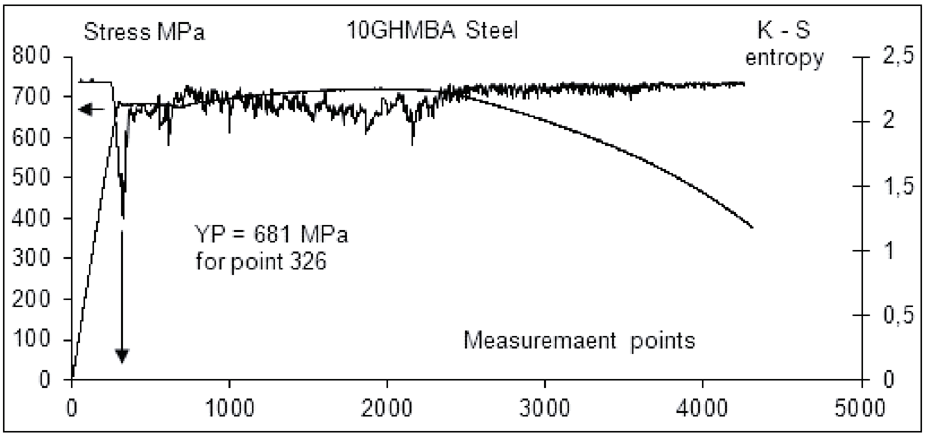

Fig. 9. The graph of stresses and K - S entropy of stresses in a function of consecutive measurement points for 10GHMBA Steel

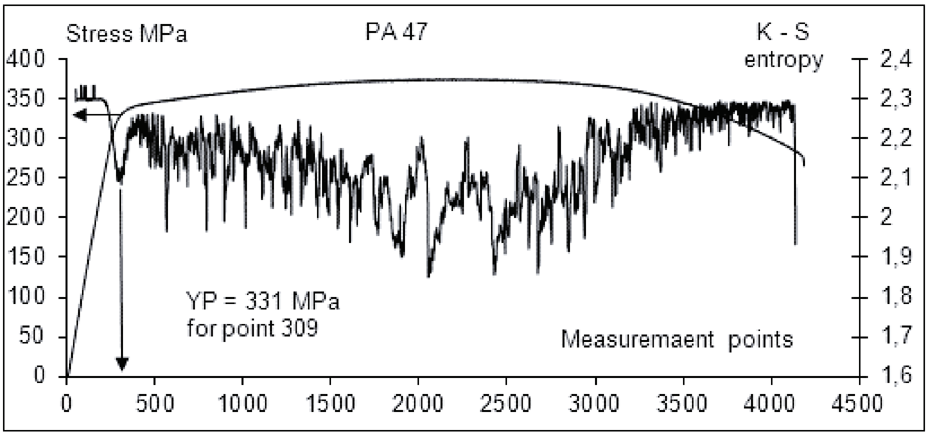

Fig. 10. The graph of stresses and K - S entropy of stresses in a function of consecutive measurement points for PA 47 alloy

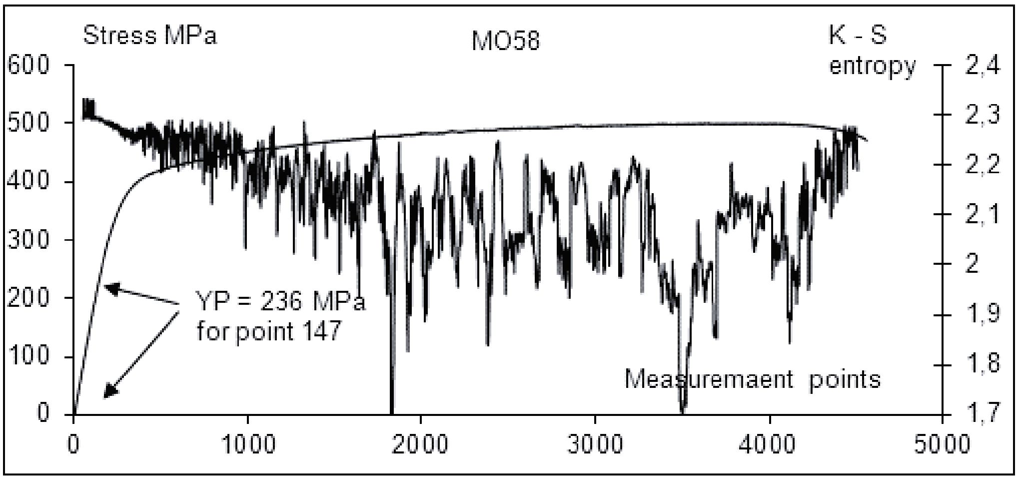

Fig. 11. The graph of stresses and K - S entropy of stresses in a function of consecutive measurement points brass M058

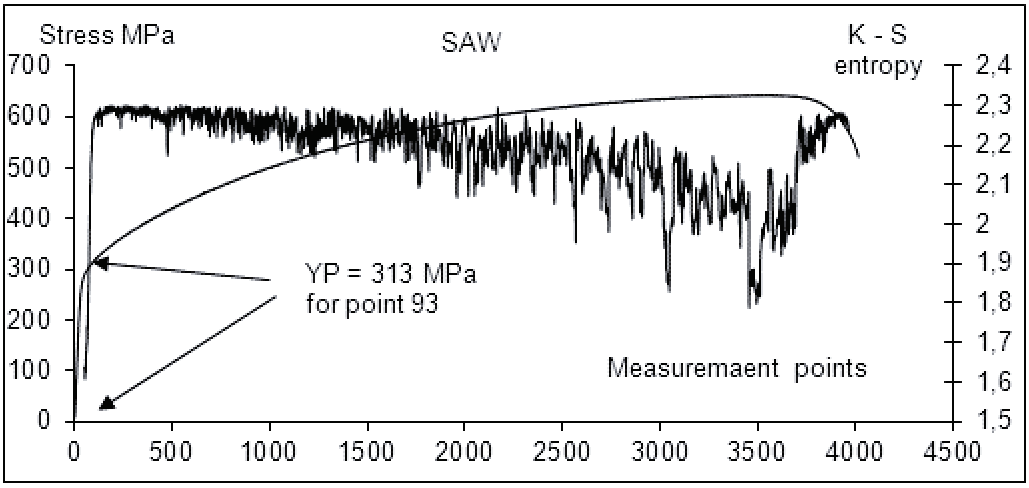

Fig. 12. The graph of stresses and K - S entropy of stresses in a function of consecutive measurement points for SAW

8. Conclusions

Application of metrical entropy in determining the yield point of structural materials makes the conventional character of this value more objective. Owning to a numerical character of proposed procedure of determining the yield point, one can find it also practical to use that method with the reference to determining variations of yield point caused by the development of damages of constructional materials' structure that are being periodical loaded.

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