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FRACTURE MECHANICS

APPLYING THE ELECTROINDUCTIVE METHOD FOR THE INVESTIGATION OF BRITTLE FRACTURE IN METALS

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1. Introduction

The potentialities of the electroinductive method for the investigation of changes in the physical and mechanical characteristics of metals have long been known. Relatively less are its applications in the field of brittle fracture and particularly in determination of their critical parameters [1, 2]. As it has already been shown [2], this method possesses a very high sensitivity and selectivity when the following two characteristic values of the brittle – fracture force in metals are identified – for the initiation of its stable and unstable propagation.

In the engineering practice worldwide there are already many methods of determining the main characteristics during fracture; some of them even being standardized. Most of these methods require a considerable quantity of specimens and are also labour-consuming and expensive. That is why together with them the so called express methods, using one or a reduced number of specimens are applied.

The purpose of the present work is to show the potentialities of the electroinductive method for the investigation of crack initiation and propagation under static loading by using additional, easily realizable experiments.

2. Experimental part

The essence of the proposed method is that two specimens are placed into two identical coils. Only one of these specimens is subjected to a mechanical load and as a result its physical and mechanical characteristics are changed. In their turn the latter change the coil inductivity. The two coils are connected in a bridge circuit (Fig. 1), when its balance is disturbed, an electric signal is generated. This signal amplified by the corresponding amplifier as well as the signal from the load cell are transmitted to an $X-Y$ recording device or to a following device for electronic processing. A set of force-electric signals $P-U$ are obtained. The first specimen is tested until fractured. The second one is loaded up to a force value which has created a definite crack propagation, the crack is fixed and the specimen is statically brought to fracture. The characteristic obtained is "force-crack length" or "force-crack propagation". It is possible to observe and measure the crack sidewards as well as to investigate it in a metallographic way.

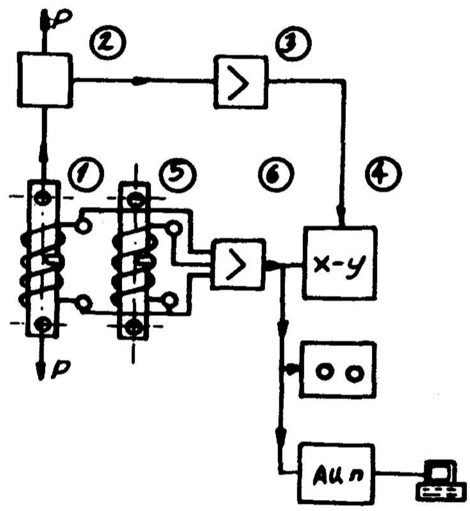

Fig. 1

The tested specimens are shown in Fig. 2. They are loaded in tension by the help of the universal testing machine of the companies Instron, MTS, TSV or on a stand which has been manufactured especially for this purpose. The loading rate is from 0.5 to 1.0 mm/min. The specimens are as delivered, without any thermal treatment. They all have a standard concentrator but without a fatigue crack.

The materials, tested, are the following steels: St-20, St-65G, St-40x, St-45, St-1x18H9T.

A fatigue crack is created on the specimen made of 65G-steel by using a machine with a pulsator of the company SCHANK. The crack propagation is performed in accordance with the requirement of the standard ASTM E399-83.

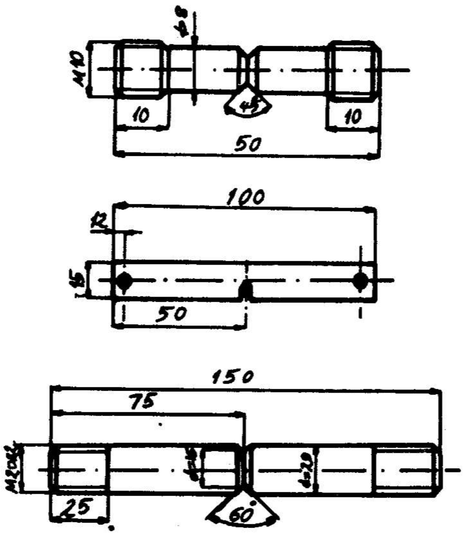

Fig. 2

3. Discussions of the results

A typical experimental diagram of the "force-electric signal" relationship from the test of a specimen made of 65G- steel is shown in Fig.3.

Five characteristic zones delimited by the points A, B, C, and D, can be noticed in the diagram. In the initial zone, OA, the diagram shows that the electrical properties of the materials improve with the load growth. In the AB zone a stabilization of the electrical signal occurs, and the electromagnetic and mechanical properties of the material are also stabilized. In the vicinity of point B it is probable that a certain destruction (micro- and macrocrack) of the material and a deterioration of the magnetic permeability begin. The direction of the electric signal changes and it begins to diminish with the force growth.

The metallographic observation on microsections of a material taken from the concentrator tip at "frozen" loading before and after point B is given in Fig. 4. In this micrograph a clearly changed structure oriented along the concentrator plane and a visible macrocrack in the area of changes can be seen. Taking into account the above paragraphs the force corresponding to point B can be assumed as a force of the initial crack opening, P_i . In the zone from point B to point C the electric signal diminishes almost linearly with the force growth – this is the zone of stable crack propagation. In point C or a little bit after it the loading force reaches its maximum, P_{max}, then an irreversible "yield" of the electrical signal occures as well as specimen fracture in point D. For the force corresponding to point C and/or P_{max} it can be assumed that it marks off the zone of the unstable crack propagation – P_c. The diagram of low-carbon steel, ST-20, is analogous to that of ST-65G and the same points delimiting the above described zones can be plotted on it.

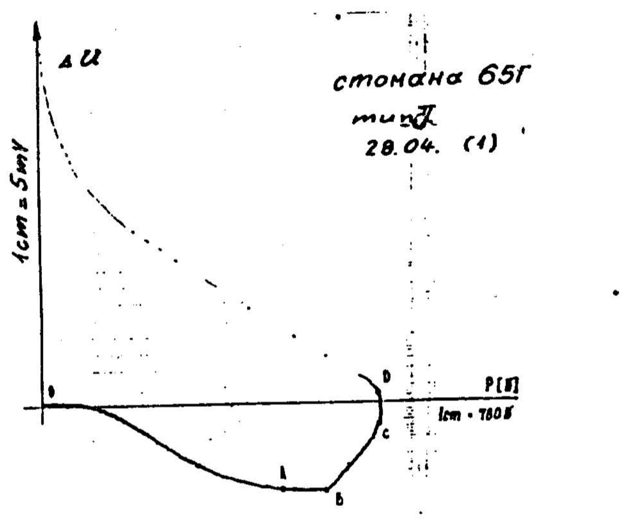

Fig. 3

The comparison of the four curves (Fig. 5) obtained by testing specimens of the same material demonstrates a high degree of overlapping. On these grounds it can be assumed that this method features a high reproducibility and reliability of the measured values.

An experiment with a crack preliminarily made through static loading is shown in Fig. 6. The procedure is as follows: a specimen is placed on the testing machine and loaded to a little bit after point B until a crack with the necessary length, for instance 1 – 1.5 mm, is obtained; the specimen is unloaded to zero; it is awaited for about 3 – 4 min and the indications are reset to zero; a new loading with the same rate is started until the specimen fractures. As it can be seen from the diagram in Fig. 6 the plot does not practicaly deflect from the abscissa with the load increase and moves parralelly to it up to the load, determined by point B. After that the plot begins to deviate almost linearly and at small angle from the abscissa. This continues until a value, corresponding to B is reached, where the slope changes abruptly to a new increase. The plot retains its linearity but with a steeper slope. If assumed that during unloading the crack was partially closed and the second loading led to its false

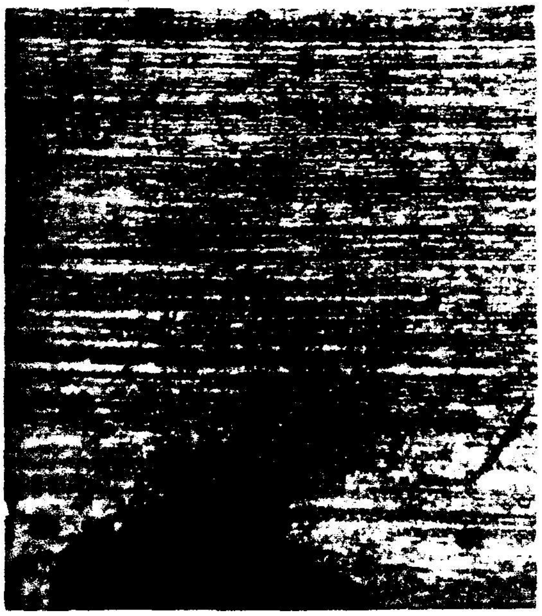

Fig. 4

opening, this would agree with the linear form of the plot at the smaller slope. When a load, corresponding to point B is reached, a real crack propagation begins again which corresponds to the line of steeper slope. The stable crack propagation continues in the manner described earlier.

The comparison of the BC straight line with its analogous one in Fig. 3 demonstrates their complete coincidence in slope and length. All this could be represented as a hypothesis for the invariance of the line of stable crack propagation, regarding a specimen with or without fatigue crack.

The "force-electric signal" relationship from the testing of a specimen with a fatigue crack preliminary made is shown in Fig. 6, curve 3. When the lengths of the static and fatigue cracks are of the same order, the results for the force of crack initiation and its stable propagation are quite near.

4. Conclusions

1. An express method for determining the crack resistance of materials on the basis of the electroinductive approach has been developed.

2. The possibility of using this method for the investigation of low- and medium-carbon steels has been verified.

3. The possibility of using reduced number of specimens has been proved.

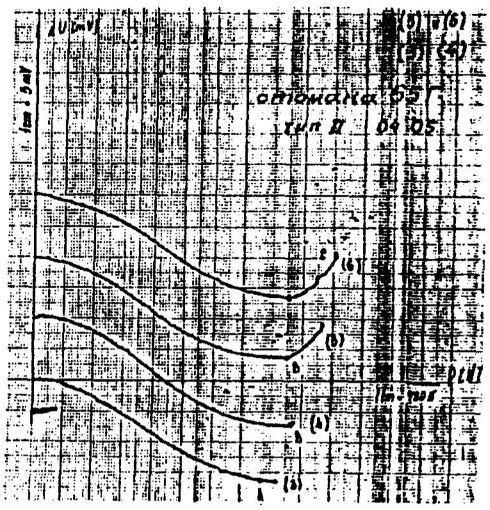

Fig. 5

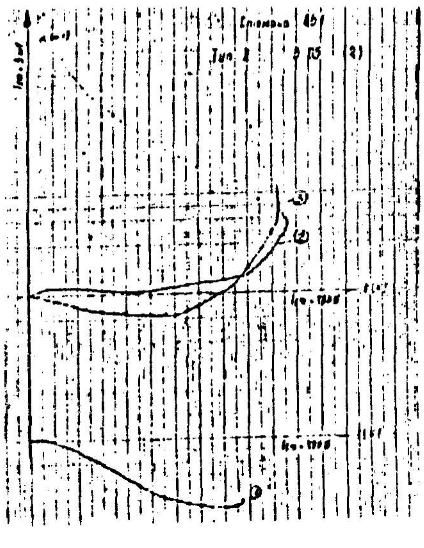

Fig. 6

4. It has been proposed to replace the fatigue crack by a crack formed through static loading.

5. An opportunity has been found out to pass from the "force-electric signal" relationship to that of "force-crack propagation" and to determine P_{init} , P_c and the relationship between K_c and P_c in only one experiment.

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