MEASUREMENT OF ULTRASONIC VELOCITY FOR STRAIN EVALUATION OF TENSILE STRESSED LOW CARBON STEEL SPECIMENS

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ИССЛЕДОВАНИЕ СКОРОСТИ УЛЬТРАЗВУКА ДЛЯ ОЦЕНКИ ДЕФОРМАЦИИ ОБРАЗЦОВ НИЗКОУГЛЕРОДИСТОЙ СТАЛИ, ИСПЫТЫВАЕМЫХ НА РАСТЯЖЕНИЕ

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Introduction

Non-destructive testing is an important part of quality control on any stage of the lifecycle of the industrial products. By definition non-destructive testing is the testing of materials for surface or internal flaws or metallurgical condition, without interfering in any way with the integrity of the material or its suitability for service. The technique can be applied on a sampling basis for individual investigation or may be used for 100% checking of material in a production quality control system. Also various NDT methods have been developed, each one having advantages and limitations making it more or less appropriate for a given application. With the variety of NDT methods available, it is important to select the method that will provide the successful results. A combination of different NDT tests may be applied to provide assurance that the material or component is fit for use.

The inspection during operation is a more complex task because the vehicle should be stopped, sometimes it should be disassembled, which lead to financial losses. Wherein the NDT diagnostics with defined gap of time shows that the damages occur in small amount of tested objects while time and funds for inspection of the rest were wasted. However the inspection intervals cannot be expanded because the structures where the damages have been already nucleated can experience the catastrophic failure which is inappropriate for different application: aerospace, petrochemical, etc.

Recent years the NDT scientific and engineering community is being increasingly interested in research and development of the Structural Health Monitoring (SHM) systems [1]. Structural health monitoring is a in-situ non-destructive sensing and evaluation method that uses a variety of sensors attached to, or fixed on structure to monitor the structural response, to analyze the structural characteristics for the purpose of estimating damage/deterioration and evaluating the consequences there of on the structure in terms of response, capacity, and service-life.

Various types of data (either continuously or periodically) from the sensors are collected, analyzed and stored for future analysis and reference. The data can be used to identify damage at its onset, to assess strength and integrity, and therefore the performance and safety of the structure [2]

The SHM can be used to expand the inspection intervals if the system doesn’t register the significant changes exceeding the defined threshold. There are different SHM principles proposed by different research groups, e.g.

the strain sensing using optical fiber [3]. The obtained value is compared with the baseline of non-damaged structure thus revealing the damage. These systems should register the data during whole operation time (e.g. during aircraft take-off, flight, landing and taxiing). Another SHM approach [4] utilizes the network of ultrasonic transducers embedded in the structure being applied for direct detection of discrete damage (BVIDs and delamination for CFRP, cracks in metal alloys, etc.). Online monitoring for such systems is unnecessary moreover it can be distorted due to noise and vibration, so the initial data is obtained after defined lifetime intervals. These systems [5] are used for operational load monitoring and can expand the inspection periods.

All SHM approaches require the development of complex algorithms and software for data processing and continuation of operation decision-making. The basis for the software is a deformation mechanics of different materials. To test the designed system and software the joint consideration of experimental data and computer modelling is required.

The present paper deals with the investigation of the velocity of ultrasonic waves during the tensile testing. The experiment was carried out to assess the change of the velocity of Rayleigh waves during loading of the specimen at different stages: elastic deformation, plasticity and fracture.

Materials and research technique

The specimens for tensile testing were manufactured from low carbon steel plate according to the dimensions presented on Fig. 1. The surface of the specimen was polished to the mirror state quality for good acoustic coupling. Two semicircular notches were used as stress concentrators to localize the strain and fracture in the middle area to be characterized during whole tensile testing using ultrasonic velocity measurement equipment.

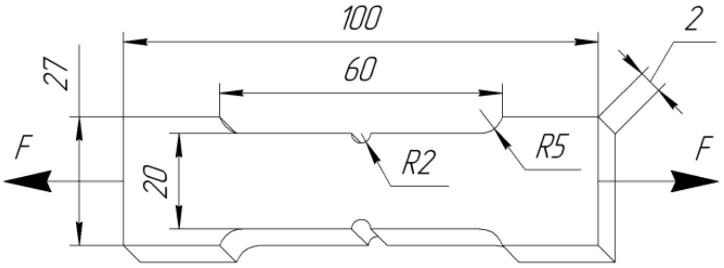

Fig.1. Specimen dimensions

The device used for ultrasonic velocity measurement is an ASTR that utilizes the ultrasonic recirculation method. The device is used for non-destructive evaluation for residual stress determination of different metals and alloys. The functioning principle is the following: the close circuit of the device transmits pulses to generate surface acoustic waves (Rayleigh waves) using piezoelectric actuator in the combined transmitting-sensing transducer (Fig. 2), then the waves travel through the gage section of the steel specimen to the receiving piezoelectric sensor located on the opposite side of the transducer and they are converted to an electrical signal. Then the signal is analyzed and compared to the reference. If the amplitude of the sensed signal is higher than the defined threshold the device generates the next pulse and so on providing so called auto circulation. Since the distance between the actuator and the sensor is fixed the auto circulation frequency will characterize the velocity of propagation of ultrasonic waves in the specimen. The device uses the 2.5 MHz frequency for generating the Rayleigh surface waves in order to characterize the elastic and plastic deformation of the tensile stressed steel specimens by registering the changes of the ultrasonic propagation velocity during whole testing.

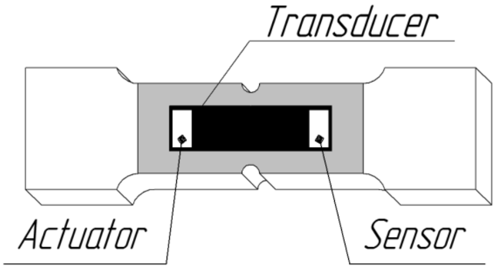

Fig. 2. Arrangement of the transducer

Specimens were tested under static uniaxial tension at Instron 5582 universal electro-mechanical testing machine with maximum loads up to 100 kN. The testing was performed with the constant strain rate with the speed of 0.3 mm/min under normal conditions. One of the most affecting factors during the test is the acoustic coupling between transducer and specimen so the mineral industrial oil was used as the immersion medium during the ultrasonic velocity data acquisition. Also for reliable measurements of velocity, it is necessary to ensure that the surface of the steel specimen must be smooth so the polishing was performed by using abrasive paper with grit size of P600, P1000, P2000 and finally with diamond polishing paste.

All recordings of velocity and elongation were performed using computer based software. The specimens were loaded until fracture thus the dependences of stress on strain and ultrasonic velocity on strain were recorded.

Results and conclusion

After the experiment the set of data was obtained and the results are represented by graphs of stress vs strain compared to the dependence of Rayleigh waves velocity vs strain (Fig. 3). It is seen that the stress-strain curve (1) is nonlinear and it is difficult to mark the elastic region due to stress concentration caused by edge notches. But the detailed examination of the initial of the static tension test can give us an approximate value of pure elastic region as ~340 MPa (0.7 % of strain) after which the plastic deformation starts to occur. The second stage of the curve is highly nonlinear, there is small necking region near fracture point where the stress decreases. The points where the ultrasonic data were recorded are easily identified as “teeth” on stress-strain curve. Because the universal testing machine was controlled by extension when the loading was stopped for data acquisition there is small stress relaxation occurred.

The ultrasonic velocity value in each point was averaged by 50 measurements. Thus the graph of average velocity vs strain (2) was obtained. The graph has two stages: the first is nonlinear starting from small decrease of velocity continues with the “jump” of ultrasonic velocity from the lowest value; the second stage is linear with moderate slope and lasts until fracture. The boundary between the two stages corresponds to the elastic limit point defined in the previous section (~0.7-1 % of strain).

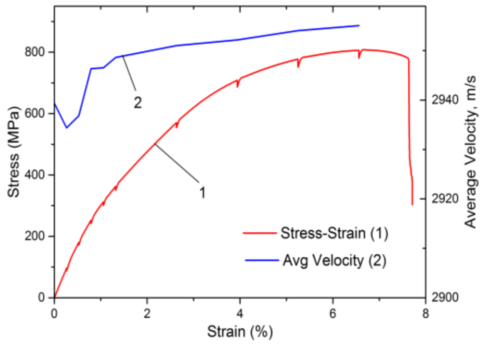

Fig. 3. Combined graph of stress-strain (1) and average ultrasonic velocity (2)

It can be concluded that the ultrasonic wave velocity depends on the stress: the velocity is different at different stages of elastic and plastic deformation. During the elastic region the velocity is flow down due to internal stress (strength of material) field on slow rate of dislocations, when the elongations of material is increasing the velocity is also increasing, and as result determine the relation between the velocity of ultrasonic waves and mechanical characteristic of materials.

This experiment of static tension of notched specimen was performed to obtain preliminary results of possibilities of ultrasonic technique to be applied for non-destructive evaluation of steel. Because the most of the structure are loaded mainly cyclically during operation the cyclic tests of specimens should be conducted. Based on the future results the investigated ultrasonic technique can be developed as structural health monitoring system.

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