System for materials testing at static loading

IOP Conf. Series: Materials Science and Engineering **618** (2019) 012048 doi:10.1088/1757-899X/618/1/012048

System for materials testing at static loading

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Abstract. This paper presents a newly developed system for mechanical testing at static loading. The separate modules of the system are described - tensile testing machine, grips, extensometers for axial end transverse deformations, electronic control system. The results obtained during tensile testing with the new system are given. The yield strength, the tensile strength, the elasticity modules and the Poisson's ratio of general purpose steal S235JRC are determined.

1. Introduction

The development of energy, chemical, aviation, automotive and other industries as well as many other branches of technology involves the use of new materials. That is why the problem of studying the mechanical properties of new materials is quite topical.

The engineering approach for stress-strain analysis is based on standard mechanical tests. The test piece made from the respective material is subjected to pure tension (compression), pure shearing, pure bending, etc. The axial force F, with which the test piece is loaded, is increased slowly until its destruction. The values of the force and displacement are continuously measured and recorded. The obtained results are used to determinate the desired mechanical properties.

In modern laboratories universal testing machines with servo-controlled loading mechanisms are used for conducting mechanical tests at static loading because they allow for precision loading [1,2].

This type of tensile testing machines is continuously modernized by implementing electronic devices and new software [3] which permit:

- Automatic control of the experiment;
- Reliable management of the test parameters during prolonged experiment;
- Recoding and visualization of the test parameters;
- Ease and flexibility of conducting different types of experiments using the properties of the machine software (for example, different types of cycling loading).

For measuring the deformations of the test piece most often extensometers are used. These devices convert the mechanical deformation in proportional electrical signal [4,5].

The devices are complex and very expensive. The purchase of off-the-shelf systems is ineffective. Experience shows that in most cases it is more viable to buy specific components and conduct in-house development of other components and software according to the goal of the tests. Thus, the team of scientists has the ability to maintain and improve the machinery during its service life. In addition, scientists are capable of assessing the effect of test machinery on experimental results, which is a prerequisite for more accurate interpretation of the test results.

The aim of the present research is to build a system for mechanical tests at static loading using available modules and to design and build the necessary additional devices.

2. System design

To conduct a mechanical test at static loading with measurement and recording of all appropriate values, the following modules are necessary:

- A universal testing machine used to conduct the static loading. A ZD10 tensile testing machine in non-working condition described below is available at the Strength of Materials Department at the Technical University of Sofia. The machine has to be modernized. This modernization is described below;
- Devices for deformation measurement. Extensometers built by Schenck (Germany) for measurement of longitudinal and transverse deformation are available at the Strength of Materials Department. The extensometers are described below;
- A control system for the new testing machine. It will include an electronic control unit used to control the testing machine and personal computer (PC). The system is described below.

3. Testing machine ZD10

Figure 1 shows a 3D module of the ZD10 universal tensile testing machine. The machine is designed to test materials at static loading. It comprises:

- Housing *1* of the reduction gear, attached to lead screw transmission;
- Two vertical columns *2*;
- Load cell *3*;
- Load cell housing *4*;
- Traverses – upper fixed traverse *5* and lower movable traverse *6*;
- Screw *7* with trapezoidal thread;
- Grips *8*;
- Main housing *9*. The power electronic unit, the power transformer, the DC motor, the analog motor control, the tube analog load cell amplifier, the mechanical system of the measurement scale *10* and the recording device *11* are situated in the main housing.

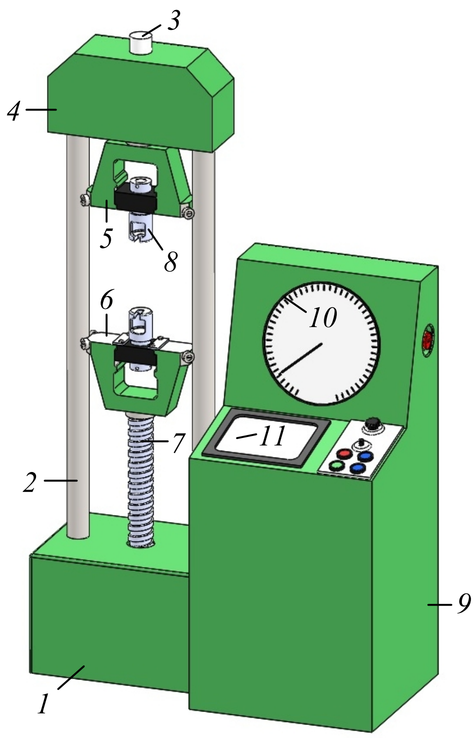

Figure 1. 3D model of the universal testing machine ZD10.

The machine is equipped with:

- Spherical grips (they allow for self-aligning of the test piece) for cylindrical test piece;
- Wedge type grips for testing flat test piece and cylindrical test piece;
- Device for compression testing;
- Device for three-point bending tests;
- Device for sheering tests.

The load cell and the electronic control unit are in non-working condition which makes the machine inoperable. On the other hand, recording of the measured values on paper is obsolete. A modernization of the tensile testing machine is required.

4. Modernization of the universal testing machine ZD10

A new strain gauge load cell is mounted. The force measuring device converts mechanical deformation into a proportional electrical signal. The elastic element of the load cell has been designed for 100 kN. The load cell is calibrated according to EN ISO 376:2011 [6].

A linear incremental encoder is mounted on the right hand-side column. It is used to measure linear displacement. The displacement measuring device generates electrical impulses whose number is proportional to the displacement. The linear encoder has a range from 0 to 800 mm.

A new servo-controlled DC motor is mounted in the main housing of the universal testing machine. The DC motor is equipped with an optical sensor (rotary encoder) with a resolution of 2000 impulses per revolution. The DC motor has a nominal speed of 2100 rpm, continuous torque of 7 Nm, a nominal voltage of 150V and a maximum current of 13 A.

5. Extensometers for measuring deformation

Figure 2 shows a 3D model of an extensometer used to measure longitudinal deformation produced by the Schenck company.

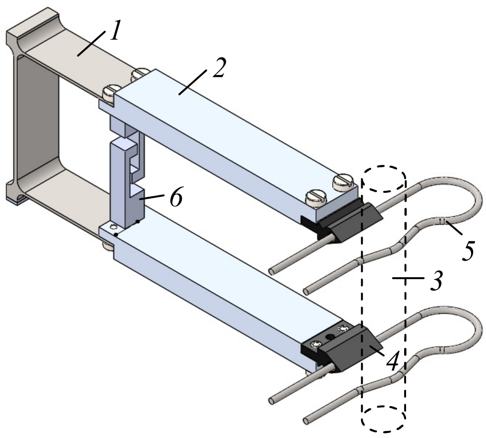

Figure 2. 3D model of an extensometer used to measure longitudinal deformation.

The elastic element *1* is attached to the arms *2*. The extensometer makes contact with test piece *3* using blades *4*, which are attached to the arms. The tight contact between the extensometer and the test piece is ensured by springs *5*. The extensometer is equipped with a number of springs suitable for test piece with different diameters. A limiter *6* is attached to the arms of the extensometer; it is used to prevent excessive deformation of the elastic element. When the test piece is deformed the arms are spread and as a result the elastic element is deformed. The gauge length of the extensometer is 25 mm. The elastic element is designed to measure deformations of ± 10 mm.

Figure 3 shows a 3D model of an extensometer used to measure transverse deformation produced by Schenck.

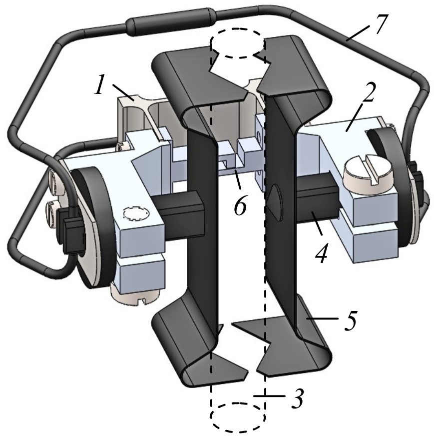

Figure 3. 3D model of an extensometer used to measure transverse deformation.

Elastic element *1* is attached to the arms *2*. The extensometer makes contact with the test piece *3* using blades *4*, which are attached to the arms. Plates 5 are attached to the blades, with are used for radial alignment of the extensometer in respect to the test piece. A limiter 6 is attached to the arms. The limiter is used to prevent excessive deformation of the elastic element. When the extensometer is mounted on the test piece the arms spread apart. As a result the elastic element is pre-deformed and when the diameter of the test piece is reduced the element strives to regain its original shape. The tight contact between the extensometer and the test piece is ensured by spring *7.* The extensometer is designed to be used with test piece with a diameter from 5 to 15 mm. The elastic element is designed to measure deformations of ± 1 mm.

The device used to measure deformation (the elastic element) converts the mechanical deformation into proportional electrical signal using strain gauges wired in full bridge. The load cell is calibrated according to EN ISO 9513:2012 [7].

6. Control system

The schematic of the used control system is shown in Figure 4. The load cell *LC*, the extensometer for measuring longitudinal deformation *E1*, the extensometer for measuring transversal deformation *E2* and the linear encoder *LE* send signal to the electronic control unit *ECU*. The *ECU* receives signal from the position limit switches *PLS1* and *PLS2*. If the limit switches are tripped, the *ECU* disengages the servo-controlled DC motor *DCM* and the reduction gearbox *RG*. To prevent external noise in the amplifier for the load cell and the linear encoder, the electronic control (*DCCU*) of the servo-controlled DC motor is mounted in separate housing from that of the *ECU*.

The *ECU* is equipped with its own memory in which the measured values can be recorded (given and measured force, longitudinal and transverse deformation and the displacement of the moving traverse). If the system works without connection to *PC*, the data is stored only in the memory of the *ECU*, which is enough for 1200 recordings. When the test is prolonged or there is a need for recording the data with a high sample rate the *ECU* is connected with a *PC*. In this case the data is transferred to PC in real time. The data is processed, visualized and recorded with specially developed software.

Using the *ECU*'s keyboard, the following parameters can be adjusted:

- Calibrating values of the measuring channels;
- Testing mode – force control, displacement control or time control;
- Loading profile – trapezoidal, sinusoidal, or triangular. For each profile the number of cycles; the beginning, maximum and ending values of loading; the loading speed in kg/min or mm/min; loading time, holding time and unloading time can be set;
- The time interval for recording the measured values.

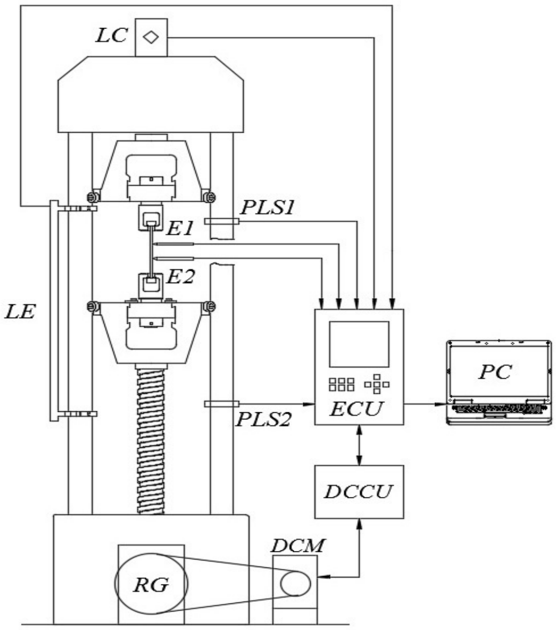

Figure 4. Schematic of the used control system.

7. Mechanical testing with the developed system

To test the newly developed system a tensile test of the test piece made from calibrated steel S235JRC is carried out. The test pieces are made from a rod with a diameter of 6 mm. The extensometers are mounted on the test piece to measure the longitudinal and transverse deformation. The general view of the test system is shown in Figure 5.

Three test piece were tested. The test pieces are subjected to pure tension while the force, longitudinal and transverse deformation are continually recoded. The testing speed was set at 1050 kg/min.

Figure 6 shows the stress-percentage extension curve of the studied steel. The rupture of the test pieces has occurred in the gauge length of the extensometer used to measure longitudinal deformation. Table 1 presents the values of the following parameters determined using the stress-strain curves:

- Tensile strength R_m – the stress corresponding to the maximum force, which the test piece can bear during testing [8];
- Proof strength, plastic extension $R_{p0,2}$ – the stress, under which the relative percentage extension is equal to 0,2%. It is determined for steel, which does not have a physical yield limit;
- Modulus of elasticity E – the tangent of the angle between the linear part of the stress-percentage extension curve and the x-axis;
- Poisson's ratio ν – the absolute value of the ratio of the transverse deformation to the longitudinal deformation in the linear part of the stress-strain curve.

The obtained results correspond to the data in the reference literature for S235JRC steel.

8. Conclusion

A modern universal system for materials testing at static loading has been developed. It can perform the following static tests – pure tension test, pure compression test, shearing test, three-point bending test. It is possible for the system to be controlled by force, by displacement or by time. A different type of loading profiles can be applied - trapezoidal, sinusoidal, or triangular. The measured values are recorded or visualized on a PC with special software.

The test results obtained with the newly developed system were given. The results show that the system can be used to determine the material properties of different materials at static loading.

Figure 5. General view of the system for testing materials at static loading.

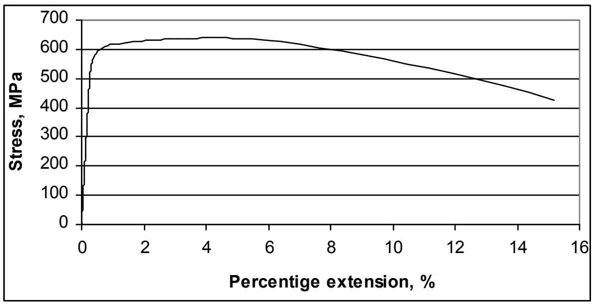

Figure 6. Stress-percentage extension curve of S235JRC steel under tension.

Table 1. Material constants of S235JR steel.

Test piece №	R_m, MPa	$R_{p0,2}$, MPa	E, GPa	v, –
1	642	597	203	0,27
2	639	591	201	0,29
3	640	587	204	0,27
Average	640	592	203	0,28

The authors would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

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