



Theory Reviews - Hardware and Software Support for Testing Material on Specimens of the Small Cross Section

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ABSTRACT

Testing techniques to obtain the mechanical properties of materials on specimens of the small cross section (miniature specimen) become the subject of numerous researches due to several advantages, in economic and organizational terms. This paper presents the model of the tensile testing device for materials on the specimens of the small cross section, its hardware and software basis. The device proved to be very reliable, so it is suitable for testing the mechanical characteristics of the material, just like the one used for the demonstration of material testing for students.

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1. INTRODUCTION

The knowledge of the basic properties of the materials has important part in the development of new materials as well as control of the quality of the materials used in design and construction [1-4]. By analyzing literature sources, it can be concluded that research in the field of material tensile testing is actual on many issues. There is more and more testing of material properties on non-standard specimens, small-cross-sectional samples [5-7], testing in the field of metal and nonmetallic materials, as well as tests carried out on small, easily portable devices [8-11], which are, as such, very suitable in the

educational sense. Research with these types of devices, with low-mass and volume specimens, is especially relevant in the testing of very expensive and rare materials.

In the paper [10], the authors presented the development and design of a small and practical tensile testing device, designed to help students perform classroom testing using a low-mass and volume samples. Tensile testing on samples is carried out at speeds of 0.001 to 1.0 mm/s, by adjusting the speed of the stepper motor.

Specimens of non-standard dimensions and shapes, of small cross-sections are generally the

dog bone type with rectangular cross-sections. Many researchers are concerned with the influence of the shape and dimensions of the specimens on the results of the testing [12-15]. Most of the authors verified their results with the finite element method. Special attention is on the problem of optimizing the small cross-sectional specimens in order to achieve the best results of the test [16-18].

Some authors [19] have proposed to construct a new steel jaw grip on the device to hold smaller specimens than standard ones, in order to reduce costs and use standard laboratory equipment for tensile testing. The new jaw grip is optional and can be used as needed.

Standard tensile testing devices are usually massive and are used in special laboratory conditions. Testing devices use standard, relatively large specimens. By using small and lightweight testing material devices that use small cross-section specimens, which are manufactured on numerical devices, both industrial and academic researchers save time and money. No special conditions and space for testing are required, there are no limitations in the number of test specimens in economic terms, and a larger number of tested samples provide opportunities for obtaining as precise test results as possible. We should not ignore the fact that the errors of the inclusions of the material are smaller in the small-mass and volume samples, which again supports the accuracy of the testing of the material itself.

Tensile test results are shown by the engineering stress-strain curves. Based on this the true stress-strain curves can be obtained in the range of large deformations. This, together with the finite element method, is the subject of research by the researchers [20-21]. Special attention is on true stress-strain after necking, when the deformations are localized and the stress state becomes complex, three-axial [22-26].

2. THEORETICAL BASIS OF TENSILE TESTING MATERIALS ON SPECIMENS OF SMALL CROSS SECTION SURFACE

By analysing the solution of classical and standard devices for tensile testing, it is concluded that the mass of the device is a large

device requiring a special installation and test area, that the testing forces are available in a relatively large range, the dimensions of the standard specimen are large, and therefore the prices of the devices and related hardware and software solutions are high.

Contrary to the standard testing devices on the realized device, they are performed on the specimen of a small cross section. Fig. 1 shows a specimen.

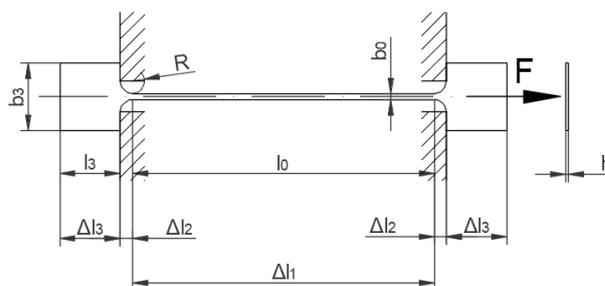


Fig. 1. Scheme of a small, rectangular cross-section specimen.

The Figure 1 shows the dimensions of the specimen before the start of the test, where: l_0 - the original length of the specimen in the parallel zone, b_0 - the original specimen width, h - the original thickness of the specimen, R - the specimen radius in fillet zones, l_3 - the original length of the specimen in grip zones, b_3 - the original specimen width in grip zones.

In small specimens, the elastic stress can be accurately calculated based from the force recorded on the device during the tensile test, while the precise measurement of the elastic strain is a challenge. Elastic strain of standard specimens can be precisely determined by extensometers, but in low-mass and volumes samples this option is aggravating and is not an option to be used. There are non-contact strain measuring systems, such as video extensometers and laser [27], but their high price and complex setting limit their application. Two alternative methods can be used to determine the elastic strain of small specimens instead of extensometers. One is the application of Digital Image Correlation (DIC), and the other is the measurement of the strain based on the measurement of the displacement of grip zone on the tensile testing device. The DIC method for strain measuring of the sample during testing is based on the comparison of sample images

before and after elongation, pixel by pixel. This testing requires the use of camera with high resolution, followed by data processing using the appropriate software. On the other hand, measuring the elastic strain of a small specimen by moving the grip does not require additional equipment and data processing. However, this method has one drawback. In measuring the displacement of the grip in order to obtain the elastic strain of the test sample, it must be appreciated that the measured elongation of the specimen includes the elongation of the specimen fillet zone and the elongation of grip zones as well.

The elongation of the tensile specimen can be divided into five zones: elongation in the measuring zone (parallel zone) Δl_1 , elongation in two fillet zones Δl_2 and elongation in the two grip zones Δl_3 .

The total elongation of the specimen Δl_u after tensile testing, as can be seen from Fig. 1, can be written as the sum of the elongation of all five mentioned zones of the specimen, as formula (1):

$$\Delta l_u = \Delta l_1 + 2\Delta l_2 + 2\Delta l_3 = \frac{F_{uk}}{E} (c_1 + 2c_2 + 2c_3) \quad (1)$$

where F_{uk} is the applied force during testing, E - Young's modulus of the material, c_1, c_2, c_3 - constants, which are in function of the specimen dimensions.

3. DEVELOPMENT OF TENSILE TESTING DEVICE AND HARDWARE-SOFTWARE SUPPORT

For material testing, a tensile testing device has been designed and developed, Fig. 2. The basic units of the device are frame construction, operating system (stepper motor, gear belt, coil spindle, receiving and guiding elements, measuring system (force and displacement sensors), the control system with the corresponding software.

The tensile testing device is a serious and reliable device. The drive system and data acquisition system are automated. The measuring system consists of a dynamometer for measuring the tensile force (4) in the measuring range from 0-400N, the accuracy of which is 1N, as well as the

measuring device for displacement (3). Measuring range of the electronic digital calliper is 0.01-50mm, and the accuracy of the calliper is 0.01mm. Data acquisition is done via AD converter (5) and Arduino Uno control unit that collects data from AD converter.

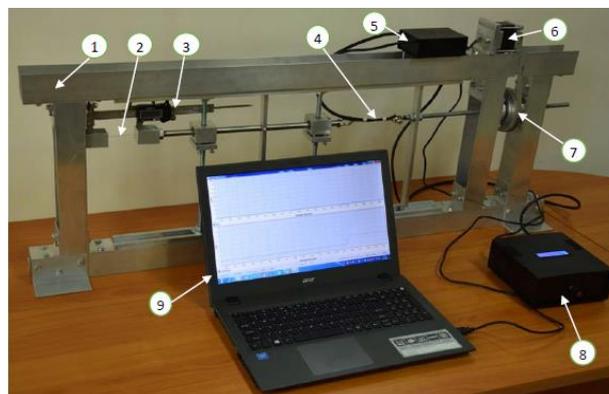


Fig. 2. Tensile testing device: 1) device frame, 2) specimen, 3) electronic digital calliper, 4) dynamometer, 5) central control unit, 6) step motor, 7) belt drive, 8) control unit for regulating the speed and direction of movement of the mobile grip zone of device and 9) the computer.

One of the two grip zones of the specimen is stationary, while the tensile force is achieved by moving the second moving grip zone of specimen in the appropriate direction. Moving the grip zone is carried out by activating the step motor (6), the speed of which is 1 mm/min.

Processing of measured data is done using the Software developed in Visual Studio 2017 using C# programming language. Visual Studio 2017 is free version and does not need to be licensed. Basically, the algorithm is given in Fig. 3.

The sizes given in the algorithm are ε_E - conventional (engineering) strain, l_{uk} - the sum of the original length of the measuring (parallel) zone of the specimen and the fillet zone of specimen, σ_E - conventional (engineering) stress, A_0 - the original cross-sectional area, ε_{st} - true strain, σ_{st} - true stress, A_{st} - true cross-sectional area of the specimen, Z - contraction (percentage reduction of area) of the specimen cross-section during testing to fracture.

Material characteristics (Young's modulus of the material, Poisson's ratio) are determined experimentally, based on measured forces and elongation at appropriate points.

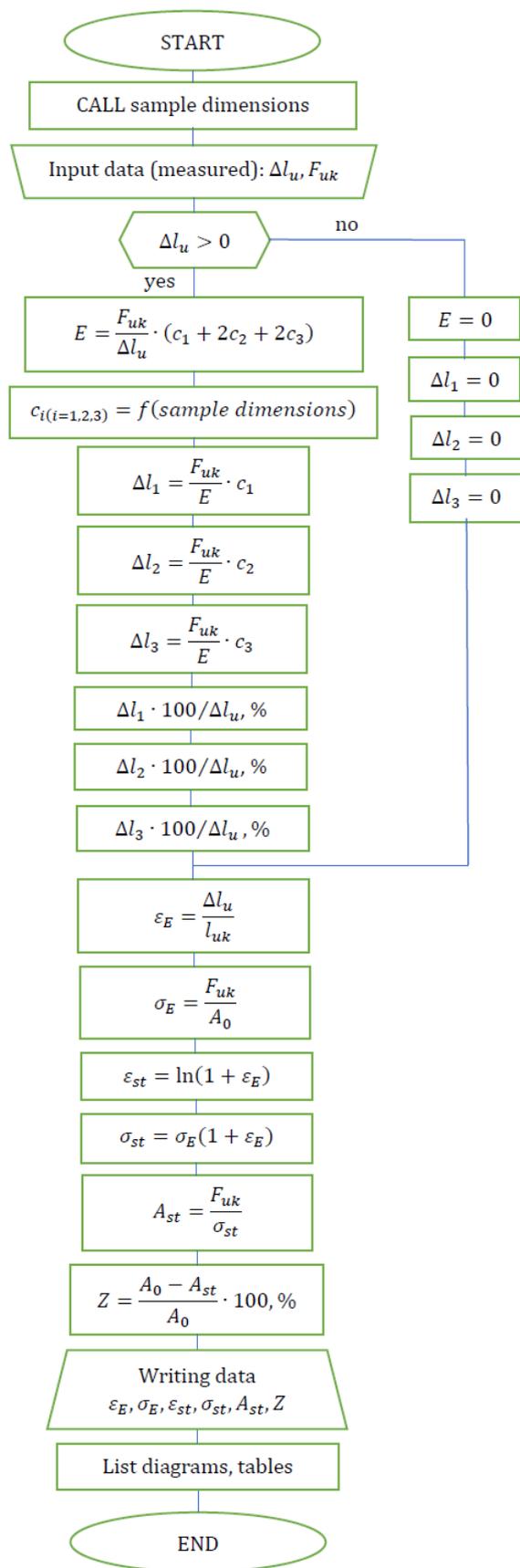


Fig. 3. Algorithm for the device software.

The true stress in the material is difficult to register, especially with the formation of big plastic

deformations, since the cross-section of the specimen during the test is constantly changing. However, if the forces are related to the current, always the smallest and most deformed cross section, the actual true stress-strain curve will be obtained. It shows a constant stress increase with specimen's cross section reduction. The true stresses and strains given in the algorithm are expressed from the assumption of a constant volume of the specimen during the tensile test.

4. RESULTS OF MATERIAL TESTING

The dimensions of the specimen are given in Table 1. The specimen material is a galvanized sheet.

Table 1. Tensile test specimen dimensions

Symbol	l_0	b_0	h	l_3	b_3	R
Value, mm	50	1	0.5	10	11	2

The specimen is dimensioned that the maximum force required for the specimen fracture is not greater than 400 N. Many specimens were tested to fracture. By statistical data processing such as yield strength, tensile strength, etc. it has been concluded that the dissipation of these values is no more than $\pm 3.5\%$, which clearly shows that the testing machine is a reliable material testing device.

Based on the data collected by measurement, a tensile force-elongation curve of the specimen can be shown, Fig. 4. After reaching the maximum force, plastic deformation is localized, a complex three-axis stress condition is created, the neck is created at the specimen cross-section, and specimen fractures develop with further growth of the elongation and decrease of force.

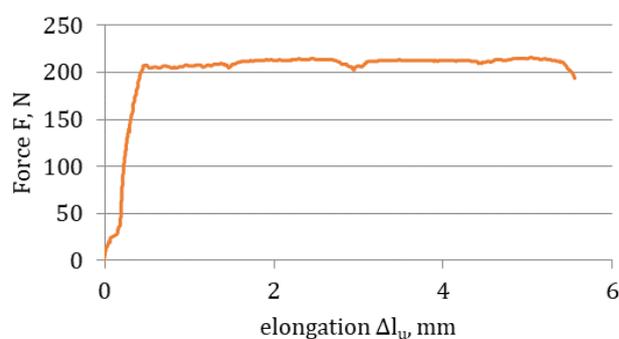


Fig. 4. Force-elongation curve.

Based on the force-elongation curve, the stress-strain curve (Fig. 5) can be obtained, which is

identical in shape to the previous force-elongation curve. The relationship between force and stress is given over the original cross-section area of specimen.

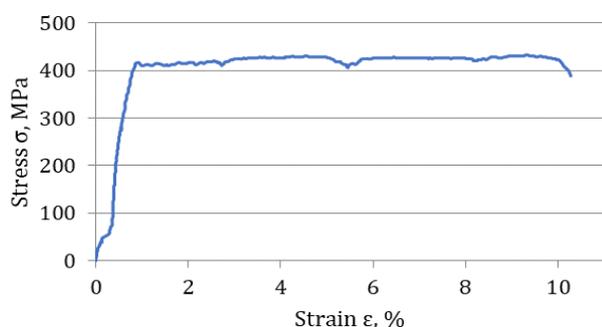


Fig. 5. Stress-strain curve.

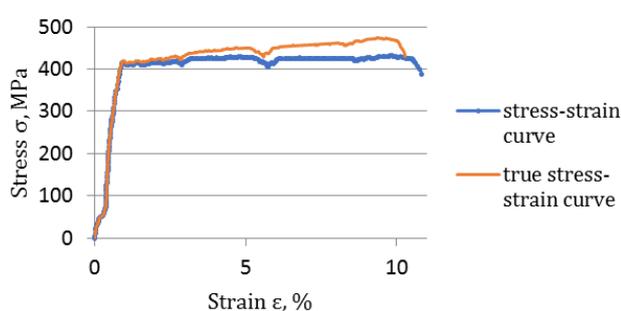


Fig. 6. Stress-strain and true stress-strain curves.

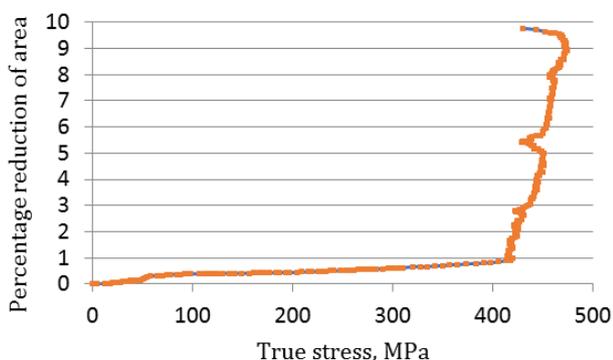


Fig. 7. Diagram of changing the cross-sectional area in the function of true stress.

Based on the presented algorithm and the analysis of the obtained results of the material testing, the elongation values in each zone of the specimen are obtained individually, for each measured value of the force. The general conclusion is that the elongation caused in the measuring (parallel) zone of the specimen (the zone where the specimen is expected to fracture) is 97.5 % of the total measured elongation. The elongation in the fillet zone is 2 % of the total measured elongation, while the elongation in the grip zone of specimen is 0.5 % of the total elongation.

By analysing the obtained data, the software prints the true stress-strain curve of the specimen, Fig. 6. True stress-strain curve is obtained by taking into account the true area of the cross-section at the moment of the plastic deformation precisely in the parallel zone of specimen.

In the case of small cross-sections, as it is here, it is very difficult to accurately measure the contraction, i.e. percentage reduction of area at the point of the specimen fracture. This value can be obtained from the measured experimental data obtained and determining the true stresses and strains. The true cross-sectional area at each measured point of force and elongation is the ratio of the tensile force and the true stresses. Thus, we can plot the diagram of the change in the surface area of the cross section in the function of the true stresses, Fig. 7.

5. CONCLUSION

The need for easy and quick education of students in the field of material testing and obtaining important mechanical properties of materials that play a decisive role in the selection of materials in construction and design have led to the development of testing devices. The device presented in this paper is relatively inexpensive, easy to handle, has automated measurement and recording processes. In addition to the educational significance, the realized device may be a device for obtaining preliminary mechanical properties of materials in various production lines without requiring special test conditions.

The designed device uses small cross-sectional specimens, non-standard dimensions, but calculated so as to fracture in the expected range of force-elongation. Specimens can be of metal or non-metallic materials.

The obtained results are comparable with the results of the renowned laboratories for tension testing of materials [28].

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