DESIGN MINIATURIZED TENSILE TESTING MACHINE

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Abstract:

The tensile properties of materials, such as the ultimate tensile strength, yield strength, elongation and elastic modulus, are very important factors for engineering designs. However, it is not easy for students to understand and evaluate the tensile properties of materials. In this study, a small and handy tensile testing machine was designed to help students conduct tensile tests in class using a miniature tensile specimen. The tensile testing machine consists of a stepping motor as an actuator, a load-cell, a load-cell amplifier, a data acquisition system and the testing machine frame. The detected load signal is amplified by the amplifier and is sent to the data acquisition (DAQ) system. The DAQ system with LabVIEW software receives the signals from the load-cell and displacement gauge. Using this testing machine, it is possible to conduct tensile tests on miniature tensile specimens at speeds of 0.001~1.0 mm/s.

Keywords: Portable tensile testing machine, miniature specimen, heat treatment, stress-strain curve

1 Introduction:

In engineering design and analysis, tensile stress-strain relationships are frequently needed. From the relationships of the material, various mechanical properties, such as the ultimate tensile and yield strengths, Young's modulus, Poisson's ratio, the elongation, and reductions in area can be obtained. Also, the true stress-strain properties, strain hardening and tensile toughness can be calculated by means of conversion using special equations from the stress-strain curve.

To conduct a tensile test, it is first necessary to consider the tensile testing equipment and specimens. The most widely used tensile testing machines are screw-driven testing machines with a moving crosshead and a closed-loop servo- hydraulic testing machine with a hydraulic actuator. However, testing machines are relatively heavy and are typically installed in a laboratory. Conventional test methods for evaluating mechanical properties require a massive testing machine and relatively large material samples.

Miniature tensile testing techniques to obtain the mechanical properties of materials have been an interest of many researchers [1-5]. Partheepan et al proposed a simple miniature disc-type tensile specimen and fixtures to hold specimens with the help of a rigid pin to predict the mechanical properties of materials [1]. They verified the feasibility of the sample geometry using finite element method (FEM) analysis.

A miniforce tester driven by a DC-servomotor with a ball-screw guide-way was newly developed for a solder ball joint shear test by Chao and Liu [2]. The full-scale displacement and maximum applied load were 100 mm and 100 kgf, respectively. The displacement resolution of the stage was maintained at 1 micron using a precision digital displacement gage closed-loop control module. LaVan developed a tensile testing system to perform tensile tests on microsamples 3.1 mm long with a gauge cross-section of 0.2 mm^2 [3]. They conducted a tensile test of samples cut from weld metal to investigate the local mechanical properties of the weld joint.

A novel tensile device compatible with a scanning electron microscope (SEM) was designed and built by Ma et al [4]. They integrated a servo-motor and a three-stage reducer for a quasistatic loading mode with a loading speed of 10 nm/s. They adopted a small lead precise ball screw with left- and right-hand threads to keep the centre of the specimen stationary during the tensile test.

Hou and Chen developed a new uniaxial tensile testing system, consisting of a closed-loop piezo-electric (PZT) actuator, a load cell, and two grippers to hold the specimen in order to investigate the mechanical behaviour of thin films [5]. However, these systems are complicated and/or much more expensive than conventional tensile testing methods.

Acquiring new instructional laboratory apparatuses and preparing samples are a challenge due to typical budgetary limitations. In addition, sophisticated skills are required to operate the testing machine, especially the servo-hydraulic testing machine. Therefore, a new approach for an easy-to-handle and inexpensive tensile testing system is necessary for undergraduate students in mechanical, civil and materials engineering, so that they may conduct tension tests easily by themselves.

In this article, a miniaturised tensile testing system involving the use of a specially designed miniature tensile specimen is proposed. The system developed was designed to convert the rotation motion of a ball screw into the linear motion of specimen grips that apply a tensile load to the specimen. The frame contains an aligned linear motion guide for the movement of the specimen grips, ensuring the co-linearity of the travel axes. One side of the specimen is connected to a ball-screw block and the other side is connected to a load-cell to detect the load magnitude. It was concluded that such an apparatus can be designed, developed and constructed in house within a manageable budget. This can be accomplished by taking advantage of the capstone senior design project.

2 DESIGN OF THE TENSILE TESTING MACHINE SPECIFICATIONS

The performance requirements of the machine were established for breaking using a 6061 aluminium alloy plate specimen with a thickness of 1 mm. In terms of the loading capacity of the testing machine, the specimen preparation and handling processes, thin miniaturised specimens are suitable. The functional requirements of the machine are as follows:

- Sample size: 1 mm thick, gauge cross-section area of 4 mm^2, and gauge length of 8 mm.
- Maximum stroke: 20 mm.
- Maximum

tensile force: 2.0

kN. DESIGN

CONCEPT

The machine is designed to pull one end of the sample, while the other end of the sample is attached to the load cell to monitor the applied load. The maximum tensile load to break the aluminium 6061 sample with a cross section area of 4 mm^2 and an ultimate tensile strength of at most 300 MPa was determined to be 1.2 kN. Thus, the maximum tensile force requirement of the machine was set to 2.0 kN. The load is measured with load cells with 0.5% of the maximum rated load.

In order to pull the sample without torsion, a ball screw converts the stepping motor rotation into linear motion. A ball screw with a diameter of 10 mm and pitch of 2 mm positioned in line with the specimen provides the tensile force. A chain is used to couple the stepping motor to the ball screw because a collinear arrangement would have made the system too long. A stepping motor with a capacity of 40 N-cm generates a full rotation in 200 steps and can be driven by the control system in 1/5 steps. A linear motion guide is adopted for precise alignment of the specimen without any distortion during gripping and tensile loading.

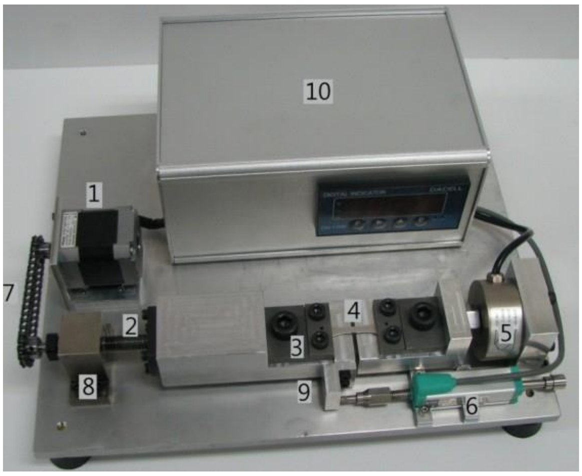

Figure 1 shows the overall structure of the miniaturised tensile testing machine.

Figure 1: Photo of the miniature tensile testing machine with a size of 330 x 280 x 155 mm: 1) stepping motor; 2) ball screw block; 3) specimen holders; 4) miniature tensile specimen; 5) load-cell; 6) displacement gage; 7) chain;

8) bearing holder; 9) linear motion guide; and 10) control box.

A special specimen holder was designed to carry out the tensile test. The specimen holder consists of two fixtures made of die steel, as shown in Figure 2. The specimen fits into a cut-out in the specimen holder. The cut-out is machined into the same shape and dimension of the grip section of the specimen, 0.97 mm deep on the holder, for easy fixing of the specimen. The fixture is provided in the form of a hole that is 10.5 mm in diameter to hold the specimen with the help of a loading pin with a diameter of 10 mm. The test specimen experiences the tensile load through the loading pin. The specimen is attached at both ends by fixing the specimen holders. The prepared test specimen fixed in, then, gripped with the help of the loading pin. The test was carried out in the present case with a speed of 0.15 mm/min. A preload of 1 N is applied to nullify the effect of any initial nonlinearity in the output of the miniature test.

A National Instruments USB-6009 data acquisition card is used to create the square-wave signal that drives the stepper motor and to acquire the analogue signals from the load cell indicator as well as the displacement gage. The application software of the system is written in LabVIEW, a graphical programming language provided by National Instruments. The graphical user interface (GUI) provides the user with complete control over all aspects of the tensile testing machine, as shown in Figure 3. When first powered up, the GUI guides the user through all of the steps necessary to conduct the measurements. Geometrical details such as the length, width and thickness of the test specimen are supplied to the software. All data gathered throughout the experiments can be exported to a text file for further processing using a spreadsheet tool.

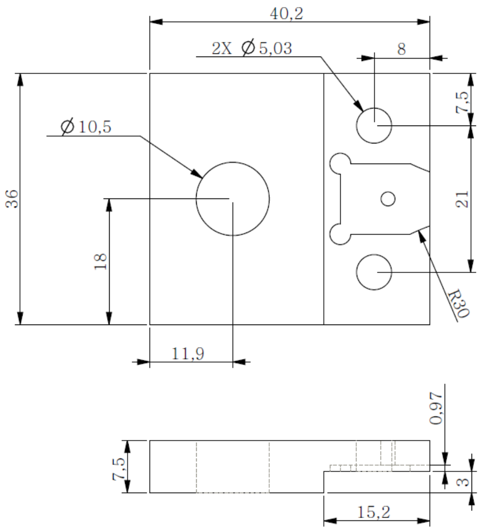

Figure 2: Dimensions of the specimen holder (all dimensions in mm).

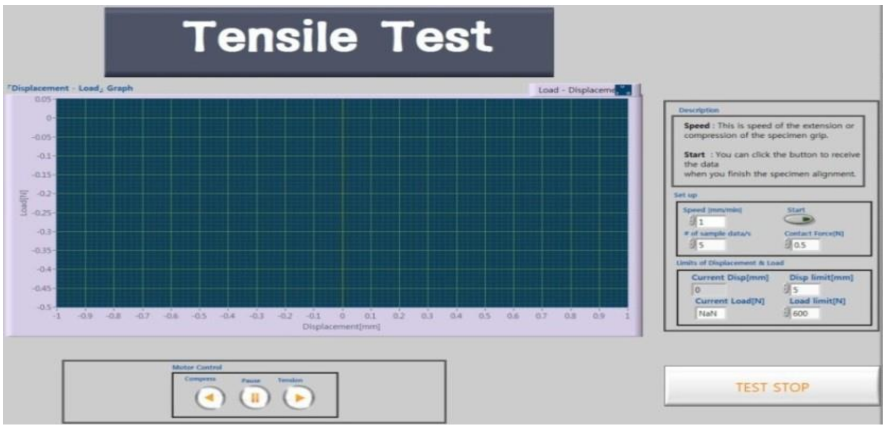

Figure 3: The user interface written in LabVIEW. The interface includes a real-time plot of the applied load against displacement. Also included are setup routines for the sample setup process.

3 SPECIMEN TESTING

In this study, a miniature specimen is designed, as shown in Figure 4. The size and dimensions of the specimen were miniaturised, based on a conventional standard tensile specimen. A finite element analysis of the miniature tensile test was carried out using the commercially available OptiStruct code in order to verify the specimen geometry without stress concentration. An elastic analysis of this test was carried out with the specimen geometry using various radii (from 5 mm to 40 mm) of gauge section of the specimen. Figure 5 shows the longitudinal stress distribution at an applied load of 500 N. The nominal stress of the gauge section with a cross-section area of 4 mm^2 is 125 MPa, as expected. The stress distribution result verifies that there is no stress concentration on the gauge section of the specimen geometry with a radius of 30 mm, as shown in Figure 5.

In order to make many specimens inexpensively for students, a punching process was adopted. The punch and die were made of SKD11 die steel. A die in the same shape as the specimen is punched on a thin plate with a thickness of 1 mm, as shown in Figure 6. The procedure for making this specimen is much easier compared with those of conventional tensile test specimens, which require a number of machining operations.

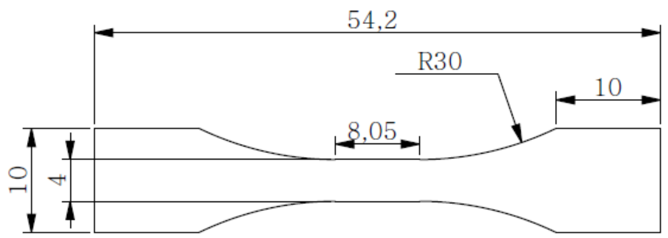

Figure 4: Dimensions of the miniature tensile specimen.

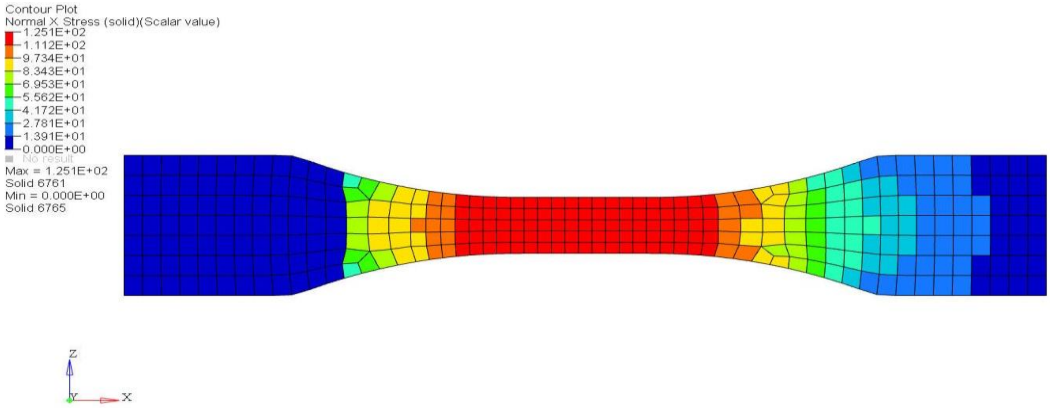

Figure 5: Finite element result of the miniature specimen to check the stress conntration.

Figure 6: Photo of the specimen using a blanking process and a blanked-out plate.

4 TENSILE TESTING AND RESULTS

Different types of heat treatment are generally utilised to achieve a good combination of strength and ductility. Therefore, in order to help students understand the effects of heat treatments on mechanical properties, five specimens were provided to acquire the optimal heat treatment condition with respect to the ultimate tensile strength. The students were supposed to conduct tensile tests of specimens, which had been heat-treated under different conditions. In order to understand the influence of a heat treatment on the mechanical behaviour, heat-treatable aluminium 6061 alloy was adopted.

The students were supposed to find the optimal ageing time for the highest tensile strength of the 6061 alloy within an aging time range. The specimens were solid-solution-treated at 803 K for 1 hour, quenched in room-temperature water and, then, underwent aging treatments within an aging range of 0 to 300 minutes. The students had to choose an arbitrary aging time from between 0 and 300 minutes, because the maximum ultimate tensile strength was found near 120 minutes according to our previous experimental results. The students were asked to provide the stress-strain curve of the tested samples and determine the optimum aging time for the highest ultimate tensile strength in a laboratory class. They also had to summarise the test results, as shown in Table 1.

Table 1: Summarised tensile test results on various aging time.

Ageing time (min.)	YS (MPa)	UTS (MPa)	Elongation (%)
0	81.1	169.5	42.3
10	150.8	258.7	27.3
30	254.2	298.5	17.5
60	276.1	302.3	12.8
120	287.8	309.9	13.3
180	274.2	297.6	13.5
210	275.2	303.7	13.7
240	245.1	282.4	15.2
300	243.2	283.8	13.9

Figure 7 presents the engineering stress-strain curves of the aluminium 6061 alloy at various aging times. Regarding the solid-solution treated sample, the ultimate tensile strength (UTS) and yield strength (YS) were 81.1 MPa and 169.5 MPa, respectively. Figure 8 shows the UTS and YS values against aging times for the solid-solution-treated aluminium 6061 alloy samples. According to this figure, the UTS and YS increased continuously up to 120 minutes and, then, decreased with increasing ageing time.

The maximum UTS of the aged treatment of aluminium 6061 alloy was 309.9 MPa, which is close to that of aluminium 6061 T6 tempered alloy [6]. Therefore, from Figure 7, the optimal aging time for obtaining the highest UTS was found to be close to 120 minutes. Compared to the solid-solution-treated sample, the UTS and YS of the aged sample with an aging time of 120 minutes both increased dramatically by 83.9% and 254.9%, respectively. However, the degree of elongation decreased from 42.3% to 13.3%. The difference in the strength and ductility is attributed to the precipitation strengthening effect from the heat treatment. From these experiments, students could understand the effect of a heat treatment on mechanical properties and could learn how to acquire the UTS, YS and elongation of materials from tensile tests.

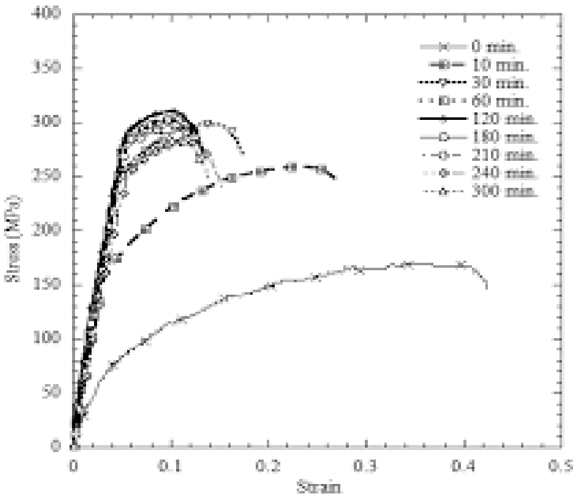

Figure: 7

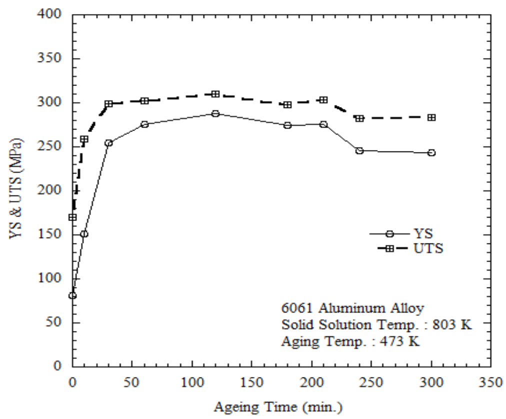

Figure: 8

3 Conclusions

This article described a method to evaluate material properties using a miniature tensile testing machine with a miniature specimen through a simple experimental setup. A portable miniaturised tensile testing apparatus was designed and developed. The newly designed specimen is small in size and easy to prepare. Finally, the developed testing system can be used as an instructional experimental apparatus to assist students in their efforts to understand the basic mechanical properties of materials.

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