10th International DAAAM Baltic Conference
"INDUSTRIAL ENGINEERING"
12-13th May 2015, Tallinn, Estonia

IMPLEMENTATION OF A TORSION TESTING DEVICE FOR 3D-PRINTED PLASTIC TUBES

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Abstract: *Usage and popularity of 3d-printed parts is increasing but printed parts usually have different qualities compared to plastic parts made with traditional methods.*
This article describes the development and construction of a device for torsion testing of 3d-printed hollow plastic tubes. The device should measure the torque and twisting angle of the test specimen until it breaks. Strength values of ABS plastic tube with outer diameter of maximum 30 mm and wall thickness of maximum 5 mm were used.
A mechanically simple and robust testing device using incremental encoder and strain gages for measurement, was constructed. The device is calibrated to measure torque from 0 to 150 Nm while twisting angle can be infinite. The device uses four-jaw chucks for mounting the test specimen, which proved not to be an optimal mounting method for cylindrical items due to slippage.
Key words: shear strength, torque measuring, plastic tube, ABS plastic, cylindrical 3D-printing.

1. INTRODUCTION

The purpose of this study is to build a torsion testing device which can measure torque in function of twisting angle. The final use of the device will be the testing of the shear strength of plastic tubes 3D printed with a new cylindrical printing method. [1] Assumption is that cylindrical 3D-printing improves the shear strength behavior of the tube. The requirements for the geometry and forces of the device are defined so, that a tube made of ABS plastic which has an outer diameter of 30 mm, can be twisted until it breaks. Inner diameter of the 30 mm tube is defined to be no less than 20 mm so the thickness of the wall will be maximum 5 mm.
Testing speed of the device should be so slow that it will not interfere normal behavior of the material [2, 3, 4]. In this case maximum testing speed will be 0.22 rpm. Due to slow testing speed and fairly high torque required, high gear ratio is needed in power transmission. Device is built so that only shear stress is applied to the test specimen, meaning that the specimen is able to move without restrictions in axial direction. The fixing method of the specimen is designed so that the specimen should not slip during the test procedure. The fixing should be done so that the specimen measured is not damaged during the fixing process.
The torque-twist response of 3D-printed tubes is very important for determining the quality of the printed test specimen and also in testing the quality of the new cylindrical printing method. This device enables comparing the qualifications between traditionally manufactured tubes and 3D-printed tubes.
Torque produces shear stress into the material. Every material has specific amount of stress they can tolerate before breaking. Shear stress is used in measuring because 3D-printed objects usually cannot tolerate twisting. [5]
There are torsion testing devices on the markets, but they are mainly designed for

thin metallic materials and very expensive. They are usually made for testing solid specimens and do not cope well with hollow specimens such as tubes. The problem is that tubes tend to collapse under tension. Therefore fixing needs special attention so that only torque affects the specimens. [2]

2. METHODS

Several motors and drive systems were considered based on the required torque and specimen geometry. A single phase induction AC motor having an integral gear reduction was selected based on performance, size and cost. Because of the single phase supply voltage the motor was easy to get functional just plugging it to the wall socket. Nominal speed of the motor is 1200 rpm and with the integral gear box it is reduced to 7 rpm developing output torque of 7,8 Nm.

A second gearbox was selected to reduce the speed even more and increase developed torque. Based on initial test specimen geometry it was estimated that approximately 150 Nm of torque would be needed to overcome test specimens ultimate shear strength of 147 Nm. A worm gearbox with gear ratio of 30:1 was selected to provide sufficient nominal torque and high enough maximum output torque.

The torque developed by the machine was transferred to the specimen using self-centering four-jaw spindle chucks with outer diameter of 80 mm. Aluminum plugs were machined to eliminate a possible yielding of the plastic tubes while compressing with the chucks.

The torsion testing device was designed to test 3D-printed plastic tubes made from ABS. The shear strength of the tube can be calculated by using von Mises equation. [5] While twisting, the length of specimen will decrease and this would cause unwanted tension to the specimen. The frame of the device was implemented so that the only stress that loads the specimen during measurement, is the stress from the torque. This was done by using linear slide in the other end of the test specimen. Since the device is designed so that the axial stresses are prevented, the von Mises equation can now be written as [5]

$$\tau = \frac{\sigma_y}{\sqrt{3}} \tag{1}$$

Where τ is the shearing stress and σ_y is the tensile strenght of the material.

The tensile strength of the ABS plastic is approximately 50 MPa [6]. The torque needed from the device can be calculated by using equation 2 [5]

$$T = \frac{\tau I_p}{r} \tag{2}$$

Where T is the needed torque, I_p is the torsion constant and r is the radius of the tube. Equation 2 gives torque that is needed to break tube made from ABS plastic. By assuming that the printed tube will not be able to take as much load as traditional ABS tube, a low safety factor can be used. In this experiment safety factor of 1,3 was used and therefore the torque needed from the apparatus is approximately 150 Nm. [5]The schematic of the device is shown in Figure 1. The device consists of AC-motor, two gears, two fixing chucks and a linear slide. The AC-motor produces the needed movement and torque which are modified with the two gears to match requirements. The test specimen is attached to the chucks and the linear slide is used to prevent the axial stresses.

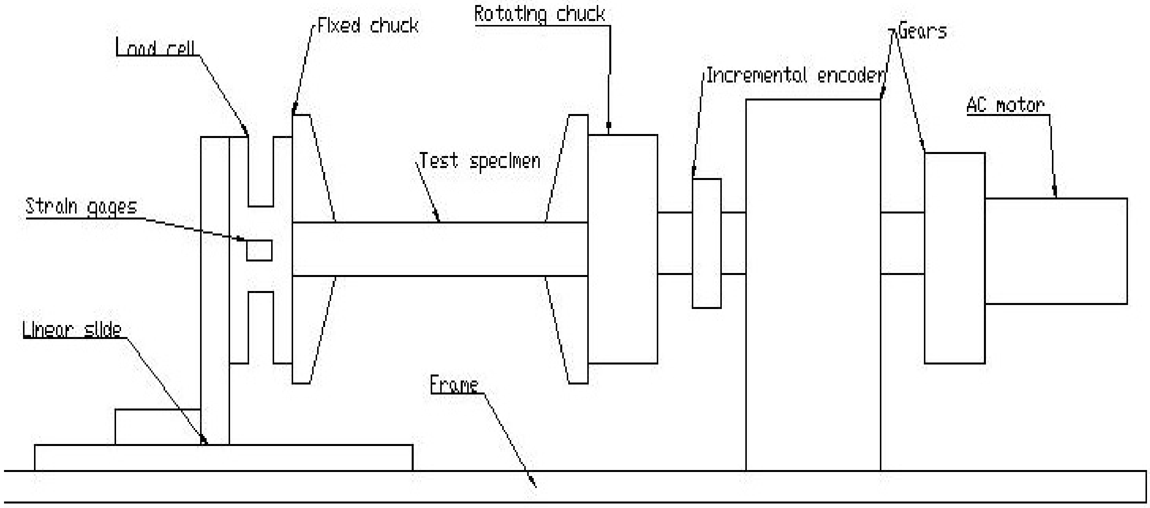

Fig. 1. The Schematic of the device.

The torque was measured with a custom made load cell and the actual measurement was done by using strain gages. Strain gages were attached to the neutral axis of load cell so that the bending stress is compensated. The gages were also aligned with main stress components. The measurement was conducted by using full Wheatstone bridge connection. In order to get precise results from the strain gages the dimensions of the load cell were designed so that relative strain in the load cell was between 0,0005 and 0,001. The relative strain applied to the load cell can be calculated by using equation 3. [5, 7, 8]

$$\varepsilon = \frac{Tr}{2GI_p} \tag{3}$$

Where *G* is the Young's modulus. The load cell was attached between the linear slide and the fixing chuck as shown in Figure 1. The calibration of the load cell was conducted by using calibration circuit that was built in to the amplifier. The output signal was adjusted to zero when no load was applied to the device. After zero regulation the calibration equivalent load was applied and the output voltage was set with reference to the calibration equivalent load.The angle of twist was measured with an incremental encoder. The incremental encoder was placed on the rotating axle. The principal of the measurement system is shown in Figure 2. For data acquisition USB-powered data acquisition box was used. It can power the incremental encoder and the amplifier of the strain gage. The resolution of the encoder was 2000 pulses per revolution. The incremental encoder was connected to the digital input of the data acquisition. The measured data was analyzed by using LabView software.The temperature of the test specimen cannot change too much during the measurement, because properties of the ABS vary a lot depending on the temperature**.** The temperature changes of the test specimen can be prevented by using very low angular velocity during the measurement. As result the device will plot the torque as the function of the angle of twist. [1]

3. RESULTS

The accuracy of the device was determined by using 50 cm bar attached to the chuck that is attached to the load cell and calibration weights that were attached to the end of the bar. Due to installation of the chuck jaws and a square shaped fixing part of the calibration bar, the bar was not horizontal in the measurements. Due to that the angle of the bar was measured before each measurement with angle rule and a water level. Calibration arrangement is shown in Figure 3.

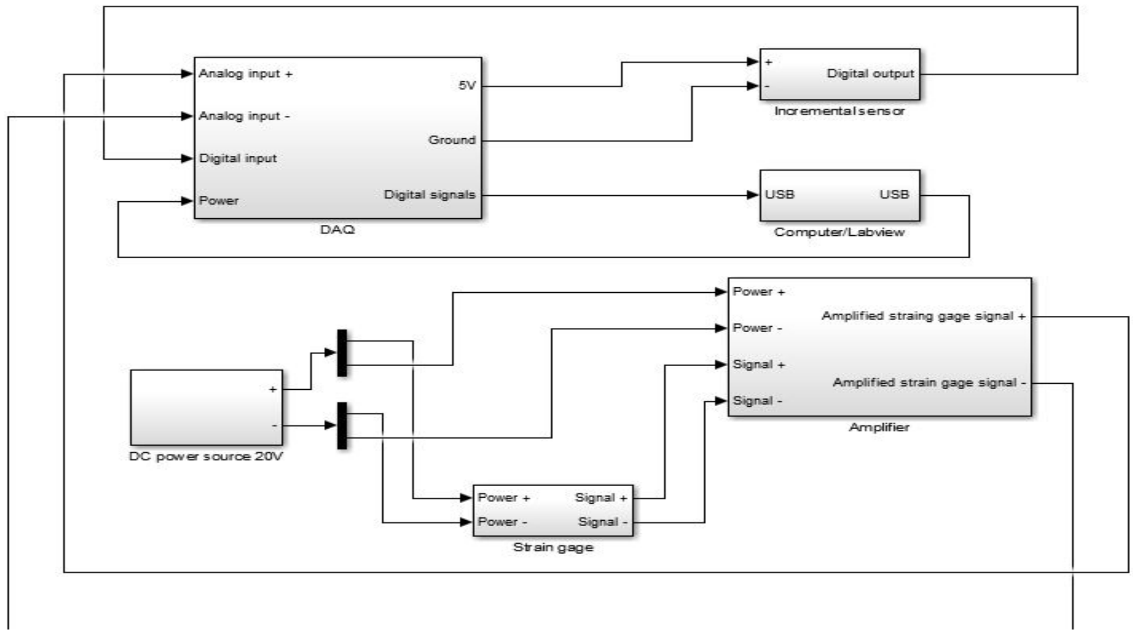

Fig. 2. The principle of the measurement system.

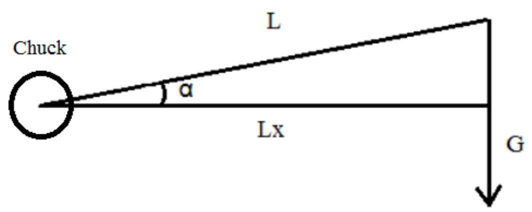

Fig. 3. Calibration arrangement.

Torque caused by calibration weight (G=mg) was calculated with formula 4:

$$M = mg\cos(\alpha)Lx \qquad (4)$$

Calibration weights, measured angles and calculated and measured torques are shown in the table 1. Difference in measured torque and calculated torque is shown Figure 4.

As a result of previous measurement, the measuring accuracy of the device between 0 and 90 Nm can be determined.

Average error between measured and calculated value was 1,3 % and largest individual error was 2,7 %.

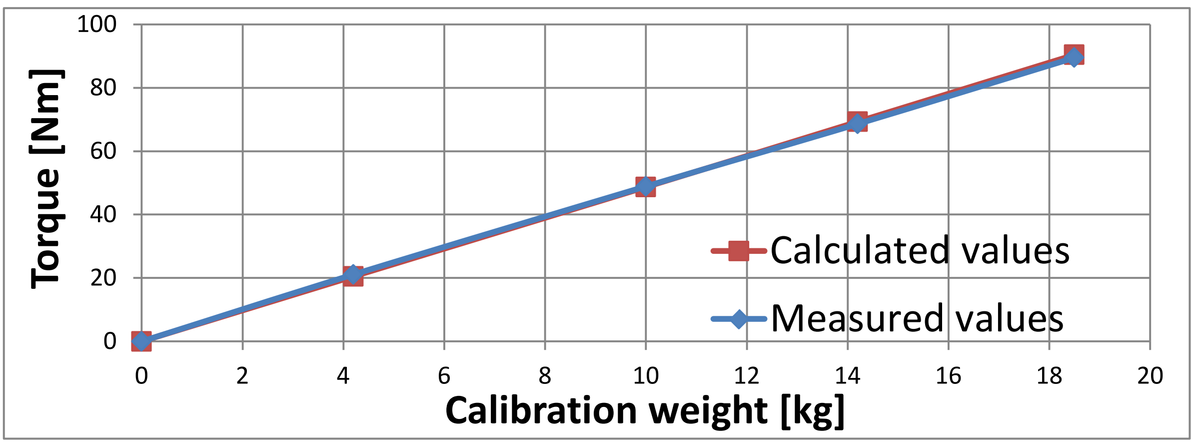

Fig. 4. Difference in measured torque and calculated torque.

measurement	m (kg)	angle (deg)	calculated torque	measured torque
1	0,0	0,0	0,0	0,0
2	4,2	6,0	20,5	21,1
3	10,0	6,5	48,7	48,9
4	14,2	4,0	69,3	68,6
5	18,5	2,0	90,4	89,5

Table 1. Measurements.

Reason for the error might be the slight inaccuracy in the angle measurement, which might cause error to the calculated values. By observing the values from Figure 4 and table 1 it can be seen that the error remains quite similar throughout the whole range.

A critical part of the torsion measurement is the fixing of test specimen. On our device the greatest concern was that does the fixing made by chucks create enough friction to prevent the slipping. It was investigated that by tightening the jaws against round surface and using a sleeve made of aluminium inside the tube, only about 65 Nm torque could be applied to the test specimen without slipping. Due to that it is recommended that all test specimen should have rectangular mounting surfaces on them.

Another concern was that will the machine be able to provide the required 150 Nm and will the structure be able to stand the stress caused by that. While testing specimen with rectangular mounting faces, we were able to achieve 95 Nm. In Figure 5 is the data plotted from that test. Y-axis is the torque and x-axis is the angle of twist in degrees.

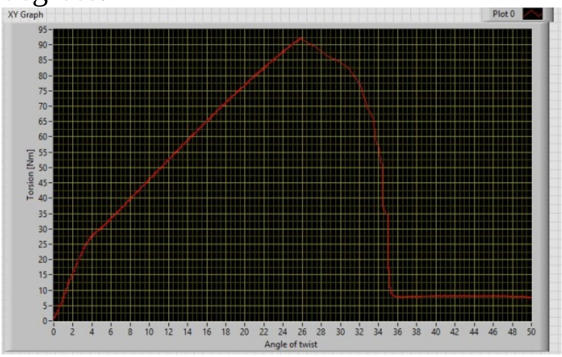

Fig. 5. Torque-angle curve with 95 Nm peak torque.

4. DISCUSSION

This torque testing device is able to twist and break the tubes up to a certain torque. The device is also able to measure the torque and angle accurately. Moreover this device was done with a low budget compared to commercial testing devices.

Based on the first tests the cylindrically printed tubes broke in a 45 degree angle, parallel to the main shear stress. Traditionally, layer-by-layer printed tubes ruptured between the printing layers. This supports the idea that the new method provides tubes that can endure bigger shear strengths [1]. More tests should be made to determine which method is better. The fixing points of the testing device should be upgraded before new tests. Also the quality of the new tubes is not yet constant enough to draw real conclusions.

The next step should be upgrading the fixing mechanism of the test device. The spindle chucks do not provide enough friction to create more than 40 Nm of torque. The current mechanism works well with tubes with square ends, but the cylindrical printer cannot produce these. Thus a new fixing mechanism has to be developed. Other improvements could include speed control for the rotation and a proper kill switch for the device.

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