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Influence of Size Effect on Torsional Strength of AA6061 Miniature Specimens

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Abstract

A Micro Torsion Testing Machine (MTTM) has been developed indigenously using sensors, torque transducers and rotary encoder for testing the torsional strength of miniature specimens. This machine is especially designed for testing specimens of Aluminium, Copper and their alloys. This machine would also be useful for testing various miniature level nuclear materials, composites and biomedical implant rods etc for their life assessment and experimental observations. In the present study, the size effect on the torsional strength of AA6061 specimens were studied by comparing the properties of specimens at micro and macro level dimensions. As the dimensions of these specimens are different, their strength and response due to torsion load were determined using conventional Torsion testing Machine and Miniature Torsion Testing Machine and then compared. The test results were observed manually and also using simulation software. For observing reliable results, the data Acquisition system is incorporated in the MTTM and conclusions were made.

Keywords; *Torsion strength, Torsion Testing, Miniature specimen, Size Effect, Torsion Testing Machine*

I. INTRODUCTION

Samples of engineering materials are subjected to a different type of mechanical tests to measure their strength in various aspects. The test results used in the following two significant purposes: 1) Engineering Design (for example, failure theories based on strength, or deflections based on elastic constants and component geometry) and 2) Quality Control either by the materials producer to verify the process or by the end user to confirm the material pattern. Generally the Mechanical tests includes tension, hardness, torsion, and impact tests. Mechanical tests often involve the deformation or breakage of samples of material (Specimen) some common forms of test specimens and loading situations are shown in figure 1.

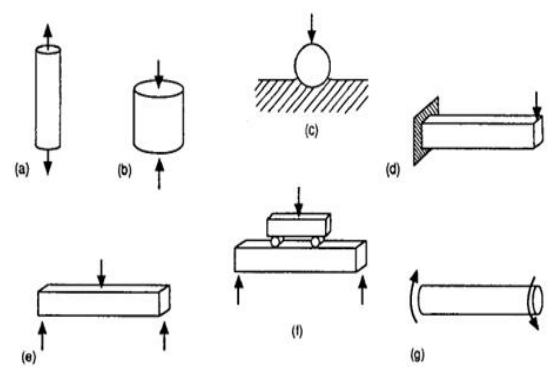

Figure 1: Geometry and loading scenarios commonly employed in mechanical testing of materials. a) tension, b)compression, c) indentation hardness, d)cantilever flexure, e)three-point flexure, f) four-point flexure and g) torsion

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In the above testing methods, a known stress or strain state is applied and the material properties are incidental from the resulting mechanical reaction. Design of a investigating specimen is not a trivial matter. However, the simplest test work piece is smooth and unnotched. More critical geometries can be used to produce conditions resembling those in actual engineering components. Notches (such as holes, grooves or slots) that have a specific radius may be machined in specimens. Sharp notches that produce behavior similar to cracks can also be used, in addition to actual cracks that are introduced in the specimen prior to testing. Mechanical apparatus used for testing range from simple, hand-actuated devices to complex, servo-hydraulic systems controlled through computer interfaces. Common configurations involve the use of a general purpose device called a universal testing machine (UTM). Modern test machines fall into two broad categories: servo mechanical (often employing power screws) and servo hydraulic (high-pressure hydraulic fluid in hydraulic cylinders) in which, the digital closed loop (DCL) control (e.g., force, displacement, strain, etc.) along with computer interfaces are user friendly. In many areas of engineering applications, materials are sometimes subjected to torsion in services, for example, drive shafts, and twisted drills. The material used in this case should require not only adequate strength but also be able to withstand torque in operation although torsion test is not as universal as tension test and do not have any standard testing procedure, the significance lies on particular engineering applications and for the study of plastic flow in materials. Torsion test is valid for testing brittle materials such as tool steels and the test has also been used to determine the forgeability of the materials by means of torsion testing at elevated temperatures.

[1] Miniature specimen test manner enable the characterization of mechanical properties using extremely small volume of the material. Though they have their origin in materials development for the nuclear industry, the miniature specimen test techniques find very promising applications in the field of remaining life assessment, failure analysis, properties of weldments, coatings etc. The miniature specimen test techniques includes development of high precision loading equipment, test fixtures, experimental design and implementation, standardization of experimental procedures, data acquisition and analysis techniques. The applications of these method for evaluating the properties of weldments, irradiated materials, aged materials and coatings have been successfully demonstrated at IGCAR [1].

The miniature specimen test techniques developed at IGCAR are mainly Shear Punch (ShP) and Ball-Indentation (BI) tests [2]. In shear punch testing method, a cylindrical punch with a flat end is forced to punch a hole in a clamped small disc specimen. The load-displacement plot obtained during the punch test is similar to that of a traditional tensile test and properties obtained by analyzing the test curve are correlated with the corresponding conventional tensile properties. The BI test method is another miniature specimen technique that requires a very small volume of test material and can be adopted for in-situ testing on real structures. In ball-indentation test, the indenter is driven at a constant speed into the test material and progressive multiple loadings and partial unloading is performed at the same test location. The applied indentation loads and associated penetration depths acquired during the Ball-Indentation test are used to estimate stress-strain values based on well established mathematical relationships. The conception of specimen miniaturization has its origin in the nuclear industry, where because of expensive and limited irradiation space, specimen sizes were miniaturized for experimental irradiation programmes in reactors. Torsion testing finds application in medical industry too for testing implant rods of small diameter [3]. So there is a need for developing a testing procedure for this miniature specimen. In that torsion testing is used to find material characteristics like shear stress, shear

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strain and modulus of rigidity.

II. TORSION TESTING:

In many areas of engineering applications, materials are subjected to torsion in services for drive shafts, and twisted drills. Besides structural applications such as bridges, springs, car bodies, airplane fuselages and boat hulls are randomly subjected to torsion. The material used in this case should not only enough strength but also be able to withstand torque in operation. Even though torsion test is not as universal as tension test and do not have any consistent testing procedure, the significance lies on particular engineering applications and for the study of plastic flow in materials.

Torsion test is applicable for brittle materials such as tool steels and the test has also been used to find the forgeability of the materials by means of torsion testing at elevated temperatures. In order to study the reaction of materials under a torsional force, the torsion test is performed by mounting the specimen onto a torsion testing machine and then applying the twisting moment till failure. The torque and degree of rotation are measured and higher torsional load is required at the higher degrees of rotation. Normally, the investigation of specimens used to cylindrical rod type since the stress distribution across the section of the rod is the simplest geometry, which is easy for the calculation of the stresses.

III. MATERIAL PROPERTIES

➢ **ALUMINIUM ALLOY 6061**

3.1. Characeristic Of AA6061:

- It has excellent joining characteristics and good acceptance of applied coatings.
- It combines relatively high strength.
- It has Good workability and Good weldability.
- It is high resistance to corrosion.
- It can withstand fatigue loads (cyclic loads) for certain time.

3.2. Properties of AA6061:

S.No	Materials Properties	Specific Valve
1	Density	2.7 g/cc
2	Hardness, Brinell	120
3	Ultimate Tensile Strength	310 MPa
4	Tensile Yield Strength	276 MPa
5	Modulus Of Elasticity	68.9 GPa
6	Poisson's Ratio	0.33
7	Fatigue Strength	96.5 MPa
8	Shear Modulus	26 MPa
9	Shear Strength	207 MPa
10	Melting Point	582 – 652°C
11	Thermal Conductivity	167 W/m-K

Table3.1: Properties of AA6061

3.3. AA6061 Material Composition

METMECH
ENGINEERS
a research lab

#11, East Street, Raghavan Colony,
Ashok Nagar, Chennai - 83
Ph: 044 43302673 / 09962034530 / 09381036654
Email ID : metmech2005@yahoo.co.in
trpartha2005@yahoo.co.in
Website : www.metmech.co.in

Date: 29.11.2013

Test Report No : MME/TR/S033/11-12

Party's Ref No : D.C.No.Nil.4501
Lab Ref. No : 8192
No. Of Samples : One Sample.
Test Required : Chemical Composition

TEST REPORT

Sample.I.D: Aluminium Bar
Chemical Composition:

Elements	% composition
Copper	0.086
Silicon	0.512
Manganese	0.021
Chromium	0.016
Nickel	0.039
Iron	0.254
Vanadium	0.022
Titanium	0.014
Nickel	0.039
Lead	0.025
Zinc	0.091
Tin	0.034
Aluminium	Remainder

Remarks: The chemical composition of the material corresponds to ASTM Grade AA6061.

For MET MECH ENGINEERS

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(T.R.PARTHASARATHY)
Metallurgist

♦ MICRO ♦ MACRO ♦ FAILURE ANALYSIS ♦ CORROSION ♦ IMAGE ANALYSER ♦ REVERSE ENGINEERING ♦ CRM ♦ MICROVICKERS ♦ TENSOMETER ♦ ROCKWELL ♦ BRINELL

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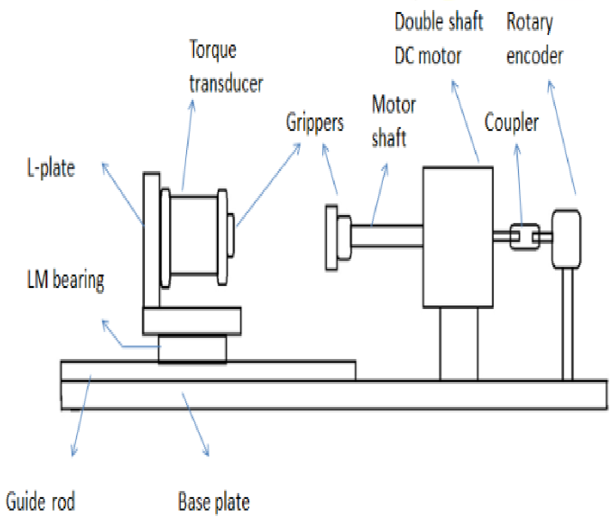
IV. DESIGN LAYOUT AND EXPERIMENTAL SETUP



The inline rotating torque sensor consists of a metal shaft with bonded strain gauges electrically connected in the form of a wheatstone bridge. Figure 5 illustrates the stresses acting on a rotating shaft subject to torsion. The strain gauges are kept on the shaft at precisely 45o to the shaft axis to sense compressive and tensile deformation due to torsion. The strain 1 and 3 must be diametrically opposite as much strain gauge as 2 and 4. In one axis at 45o angle to the axis, purely tensile stress exists, whereas 45o in other direction pure compressive stress exist. The rotor shaft is elastic and will deflect minutely under the imposed stresses. The output of the wheatstone is in proportion to torsion and hence to the applied torque on the shaft.

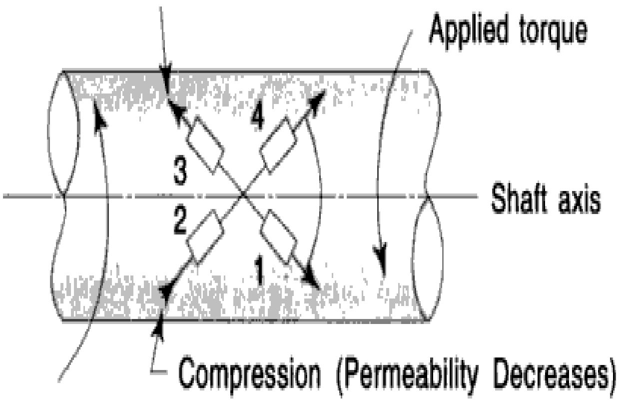


Figure 5: Shaft subjected to torsion with four strain gauges

There is electronic digital torque wrench for torque measurement. It can also be used in torsion testing both as a driver and measurement which directly give the value in display as in [6]. But it is of higher cost and it is mostly used in industries for large torque measurement. So torque transducer with four strain gauges is better sensor in terms low cost, gives precise output and easy to interface with PC via labVIEW software.

The cylindrical specimen of AA6061 is prepared with diameter of 3.5 mm. The gripping portion diameter is 7.5 mm. Two sides of the gripping portion are flattened for safe gripping to avoid any slip. Specimen is shown in figure 6 with dimension.

Figure 6: Torsion testing specimen with flattened grip

Miniature Torsion Testing Machine consists of two sensors, torque transducer and a rotary encoder. Torque transducer is used to measure torque and it is strain gauge based torque transducer with resolution of about 0.01 N-m. As from design data, minimum torque need to measure is about 0.2 N-m and maximum torque need to measure is about 4 N-m only. But torque transducer is selected to measure from 0.01 N-m to 20 N-m to do torsion testing for wide range of materials. Rotary encoder is selected to measure angle of twist with the resolution of 0.1o. As from design data, minimum angle of twist need

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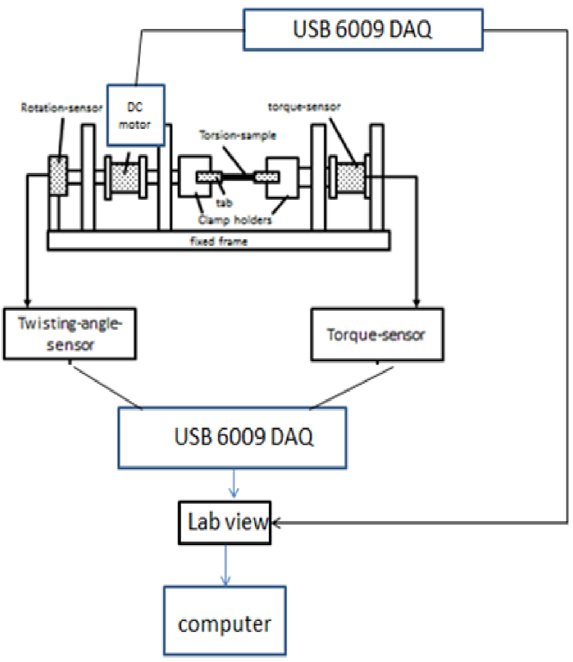
to measure is about 0.756o and maximum angle of twist need to measure is about 12.20o only. But torque transducer is selected to measure from 0.1o to 360o to do torsion testing for wide range of materials. There is no separate chuck used for gripping specimen. A slot is incorporated within torque transducer to insert specimen which provide effective transmission of torque for measurement. DC motor with gear box of torque with 200 kg-cm is selected to twist the specimen which has 20 rpm. But torsion testing require even more reduced revolutions, so decimal gear box is selected to get 2 rpm output.

A conventional torsion testing machine has motor bed to be movable along the guide way to insert specimen to chuck, since motor bed side has lower weight than non rotating side. Non rotating side consists of torque measuring dial type setup which has huge weight. Keeping less weight side movable is good for design setup. So in torsion testing machine for miniature specimen, torque transducer side (non rotating side) is kept movable. It is mounted over the linear motion bearing for linear movement to provide gap while inserting the specimen on to the chuck and to avoid any axial loads while twisting.



Lab VIEW (Laboratory Virtual Instrumentation Engineering Workbench) is a system design platform and development environment for a visual programming language from National Instruments. Lab VIEW is commonly used for data acquisition, instrument control, and industrial automation on a variety of platforms including Microsoft Windows, various versions of UNIX, Linux, and Mac OS X. Entire control of torsion testing machine is done using Lab VIEW. It is used for controlling motor and also for getting signals from torque transducer and encoder through DAQ card NI USB 6009. From the acquired values from sensors, lab view will compute and plot the graph to find shear stress, shear strain and rigidity modulus.

V. RESULTS AND DISCUSSION

S. No	TORQUE(Nm)	TWIST (DEG)	SHEAR STRESS (MPa)	SHEAR STRAIN	SHEAR MODULUS(GPa)
1	0.48	2.5	62.2	3.70 E-3	16.77
2	0.66	2.5	85.52	0.0037	23.059
3	0.88	2.5	114.03	0.0037	30.746
4	1.34	2.5	173.64	0.0037	46.818
5	1.5	21.1	194.37	0.0313	6.2095
6	1.52	25.6	196.97	0.0380	5.1862
7	1.54	38	199.55	0.0564	3.5399
8	1.58	45.5	204.74	0.0675	3.0332
9	1.6	53.2	207.33	0.0789	2.627
10	1.66	89.7	215.1	0.1331	1.6165
11	1.68	98.8	217.7	0.1466	1.4853
12	1.7	123.5	220.29	0.1832	1.2023

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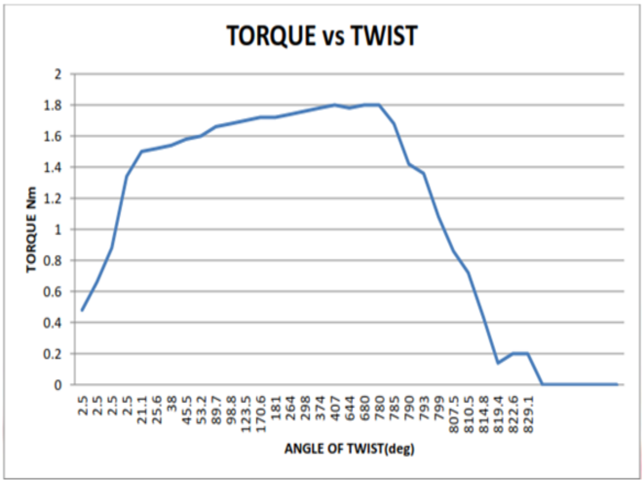
13	1.72	170.6	222.88	0.2531	0.8806
14	1.72	181	222.88	0.2685	0.83
15	1.74	264	225.57	0.3918	0.5757
16	1.76	298	228.06	0.4421	0.5158
17	1.78	374	230.66	0.5549	0.4157
18	1.8	407	233.25	0.6038	0.3863
19	1.78	644	230.66	0.9663	0.2312
20	1.8	680	233.25	1.0089	0.2015
21	1.8	780	233.25	1.1576	0.1869
22	1.68	785	217.67	1.1646	0.157
23	1.42	790	184	1.1720	0.1498
24	1.36	793	176.23	1.1764	0.118
25	1.08	799	139.95	1.1860	0.093
26	0.86	807.5	111.44	1.1983	0.0775
27	0.72	810.5	93.3	1.2039	0.0471
28	0.44	814.8	57.02	1.2106	0.0471
29	0.14	819.4	18.14	1.2174	0.0149
30	0.2	822.6	25.92	1.2226	0.0212
31	0.2	829.1	25.92	1.1945	0.0217

Table 5.1: Calculations Of Tested Specimen (3.4mm Dia) Of Aa6061

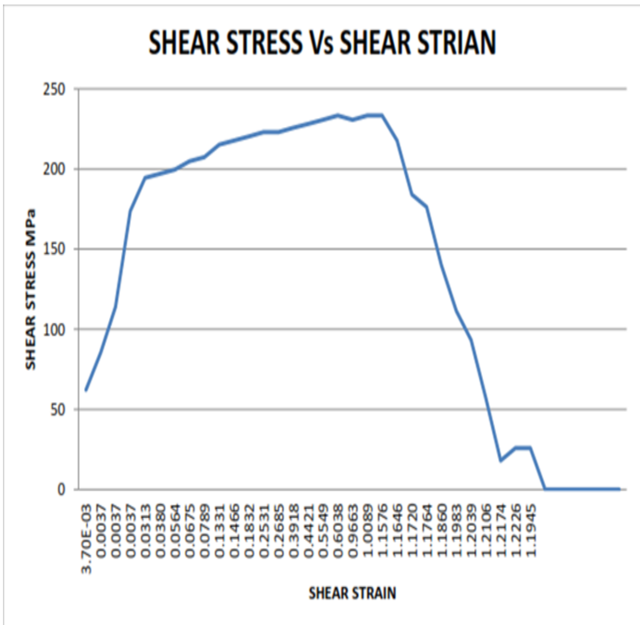
5.1. Graphical Represntations

5.1.1. TORQUE VS TWIST



Referring to the response curve between Torque Vs Angle of twist, the Tmax = 1.8N-m is required to cause the major deformation in the specimen.

5.1.2. SHEAR STRESS VS SHEAR STRAIN



Calculation ultimate torsional shear strrength:

Ꚍa = 3MMax /2πr3

MMAX = Maximum Torque

Peak torque value = 1.8 Nm (Taken from result)

r = 1.7mm

ꚌMAX = 174.93 N-mm

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VI. CONCLUSION

The Torsion test on Miniature specimens with diameter 3.5mm and with minor variations in the diameter, and 20mm length were conducted. It is observed from the results that, the specimens with minimum diameters have relatively higher torsional strength than the samples with higher diameters but with same length. Further the relationship with strength-diameter-length are to be studied and analyzed using various dimensions for the same material. In order to take the results accurately data acquisition system was thus incorporated in Micro Torsion Testing Machine.

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