Faculty of Engineering and Technology

Civil Engineering Department

Construction Materials Laboratory

ENCE215

Experiment # 11

“Steel: Bending re-bending and Tensile testing”

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- Introduction

Background information

Steel bars are commonly used in Reinforced Concrete structures, as they have a very good capability of holding tensile loads. Concrete has a very high ability to withstand the influence of compressive forces, yet, its ability to resist tension is very poor, and this shortage is usually represented in the cracking in concrete. As a result, when designing concrete, it is highly necessary to reinforce the parts which are most affected by the tensile loads of a concrete element, by placing steel bars in them. The importance of steel makes it crucial to conduct quality control tests, so as to assure the convenience of a certain stock of steel in structural usage.

The bending and re-bending test is one of the common tests usually conducted on the reinforcing steel bars. It involves the loading of steel bars using a three point flexural test procedure, followed by reloading the same bars by bending them in the opposite direction, and then observing to check for any noticeable cracks or defects that may appear as a result of the test. This test provides an indication of the ductility of the used reinforcing bars. In other words, the result of this test describes the ability of the bars to resist cracks caused by continuous bending. The test fails if the bar specimen fractures, unless this happens, the result is determined by the number of the visible cracks and defects that appear on the bar. This test is very beneficial to decide whether the used steel bars are suitable for elements that require bending, such as the beam stirrups, the joints connecting beams and columns, as well as slabs.

The other test performed in this experiment is the steel tension test . This test is performed through loading a specimen of a certain length (L_0) and a certain cross sectional area (A_0) with a normal tensile load, and observing the change of the specimen's length (δ) that corresponds to each loading magnitude. The test’s main objective is to determine the tensile strength of steel, in addition to constructing a relationship between the loading and deformation. However, it is impractical to perform the test on each element that differs in size (different L_0 and A_0), hence, rather than drawing a force-elongation curve, the values of force are turned into stress values (σ, force per unit area), and the elongation values are turned into strain values (Ɛ, elongation per unit length -dimensionless-), and therefore, a Stress-Strain diagram is constructed instead.

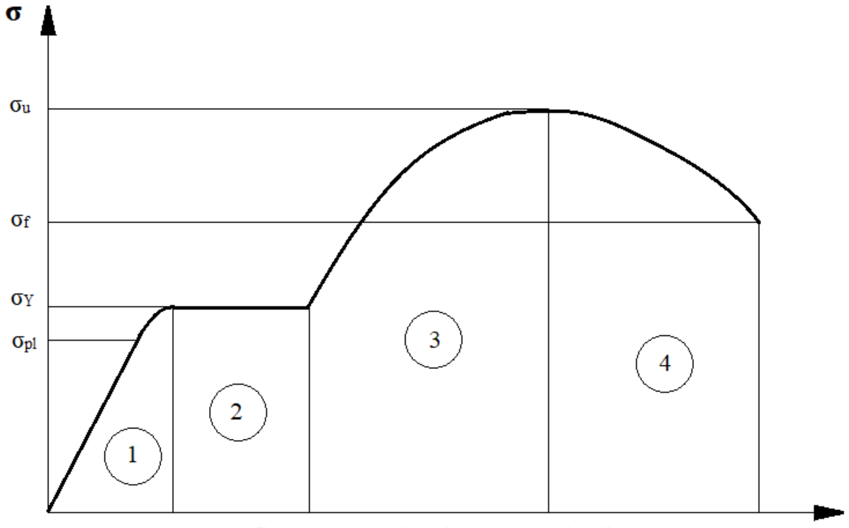
There are two types of Stress-Strain diagrams: The Conventional or Nominal Stress-Strain diagram, and the true Stress-Strain diagram. The true Stress-Strain diagram is built by using the instantaneous area ($\sigma = \frac{P}{A}$) in calculating the stress, and the instantaneous specimen length (L) in calculating the strain ($\varepsilon = \frac{\delta}{A}$). However, this type of Stress-Strain diagram is rarely used. Instead, in most engineering applications, engineers prefer to use the conventional one. Unlike the previous type, the conventional Stress-Strain diagram uses the original cross sectional area and length (A_0 and L_0) to calculate the stresses and strains throughout the experiment.

Experiments show that nearly all steel types were found to have a semi-identical stress-strain curve. This curve could be divided into four stages based on how steel behaves under loading:

Elastic Behavior: during this region, one could say that the strain is linearly proportional to the stress (in most of the region). In other words, by increasing the stress value the strain is also increased at a constant rate. The curve remains a straight line until the proportional stress limit (σ_{pl}) is reached. The term elastic means that if the load is removed while the specimen is still in the elastic region, the original dimensions of the specimen are restored. The slope of the straight line is called 'the modulus of elasticity' or 'Young's modulus' (E); and it is a unique characteristic which indicates the material's shape restoration capacity, as well as its ability to resist deformations. The relationship between the three values (σ, ε and E) is called Hook's law, and it only applies within the elastic region. (indicated by No.3 in fig(2)).

- Yielding: if the stress slightly increases beyond the elastic limit, the material loses its elasticity and starts to yield and to deform permanently. This behavior is called yielding, and it happens when the stress reaches a value called the yielding stress (σ_Y) and the deformation caused by stresses above this value are called 'plastic deformations'. It could be noticed that within this region the material keeps to elongate under the influence of the same magnitude of load. The material in this state is said to be 'perfectly plastic'. (indicated by No.2 in fig(2)).
- Strain Hardening: after yielding ends. The curve goes back to rise up, but flattens gradually until it reaches a maximum value of stress called the ultimate stress (σ_u). The term strain hardening refers to the increase in the curve, which implies that the material has gained some of its ability to resist a higher load. (indicated by No.3 in fig(2)).

- Necking: this is the region where a huge localized decrease in the specimen's cross sectional area occurs. The curve within this region starts to go down until the specimen's fail and fractures at the fracture stress value (σ_f). (indicated by No.4 in fig(2)).



fig(1): conventional Stress-Strain diagram

Purpose

1) To determine the validity of a steel bar using the bending and re-bending test, by visual inspection.
2) To build a stress-strain diagram and find other stress key values for a steel specimen using the tension test. Also, to find the modulus of elasticity for that bar.

- Hypotheses

1) Steel is a ductile material, which means it is able to exhibit significant deformations before it fractures. Hence, it is predicted that the steel bar would bend without having noticeable cracks.
2) Steel is expected to have a similar stress-strain curve of that indicated in fig(1), with a modulus of elasticity close to 200 GPa.

- **Formulas**

  - $\sigma = \frac{P}{A}$

Where:

σ: the normal tensile stress.

P: the tensile force.

A: the cross-sectional area.

  - $\varepsilon = \frac{\delta}{L_0}$

Where:

ε: strain in the specimen.

δ: change in the specimen’s gauge.

L_0: the original specimen length.

  - $U.W = \frac{W}{L}$

Where:

U.W: weight per unit length of the bar.

W: weight of the bar.

L: the length of the bar.

  - $A = \frac{\pi D^2}{4}$

Where:

A: cross-sectional area of the steel bar.

D: the diameter of the bar.

  - $D_{eq} = 12.74\sqrt{U.W}$

Where:

D_{eq}: equivalent diameter of the bar.

U.W: weight per unit length of the bar.

- **Procedure**

a) Bending and re-bending test:

1) A 16 mm diameter steel bar was placed in the machine.
2) Using the standards in table (1), the chosen diameters of axis were 64 and 100 mm for the bending and re-bending respectively.
3) The distance between the rollers was also chosen from table (1) to be 204 mm with an allowable range from 196 to 212 mm.
4) The load was applied on the bar using the lever arm, with an upward and downward movement to increase its magnitude.
5) The bar was being bent continuously until it formed a right angle.
6) The bar was placed in the oven at 100 C^o for one hour in preparation for the re-bend.
7) The bar was taken out from the oven after the hour. Then, it was placed in the machine with the guidance of table (2).
8) The bar was re-bent until it reached an angle between 100^o and 120^o .
9) The bar was then visually inspected in search for any visible cracks, defects or any other irregularities in the rounded corner.

b) Tension test:

1) A steel bar of 16 mm dia. specimen was prepared with a length of 600 mm.
2) The bar was weighed using the electric balance.
3) The equivalent diameter was calculated using a standard formula.
4) The grips of the bar were determined by leaving a saw mark at a 150 mm offset from each end of the bar.

5) The bar grips were attached to the tensile machine, and the necessary values (equivalent diameter, length, weight and other values) were input to the computer software.
6) The machine was turned on, and the bar was subjected to a tensile load.
7) The software automatically calculated the key values and plotted the stress-strain diagram. At the same time the behavior of the specimen during the four phases was observed by eye. (note: when the necking phase starts make sure to cover your ears, since the sound of fracture is very loud and sudden).
8) After the bar fractured, the two pieces were joined together (like a puzzle). And the distance between the two bars was measured again, and then entered into the software.
9) The stress-strain curve and the other outputs should be printed. But in our case they were photographed instead (the printer was off).

- **Instruments**

Apparatus and Tools:

fig(2): 16 mm steel bars

fig(3): bending machine

fig(4): steel saw

fig(5): electric balance

fig(6): tension machine

fig(7): rollers (64 and 100 mm)

fig(8): gloves

fig(9): oven

fig(10): measure meter

- **Data & Calculations:**

Table (1) shows the data related to the tension test:

Table(1): the tension test data

Description		1	remarks
Dia.(Nominal) (mm)		16	
Length (mm)		600	
Weight (gm)		946	
Unit weight (kg/m)		1.58	
Area (mm)		200.71	
Dia.(equivalent) (mm)		15.99	
Yield	Yield strength (MPa)	407.9	
Tension	Tensile strength (MPa)	580.5	
Initial length (L_0) (mm)		299	
Elongated length(L_1)(mm)		359	
Ultimate strain (ε) (%)		20.07	
Young's modulus (E)(GPa)		121.59	

- $U.W = \frac{946}{600} = 1.58$ kg/m.
- $D_{eq} = 12.74\sqrt{1.58} = 15.99$
- $A = \frac{\pi * 15.99}{4} = 200.8$
- $\varepsilon = \frac{359 - 299}{299} * 100 = 20.07$

The slope of the linear elastic region was computed by the software:

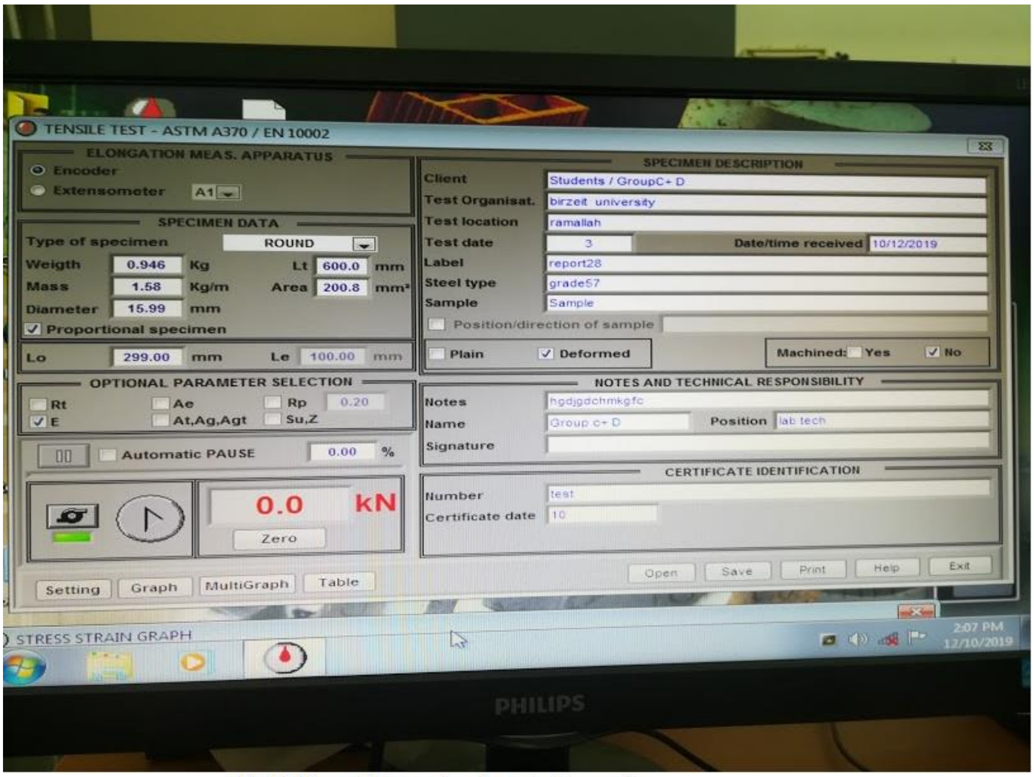
$E = 121.59$ GPa.

The stress values were also obtained from the software as in fig(11,12):

$\sigma_u = 580.5$ MPa.

$\sigma_Y = 407.9$ MPa.

$\sigma_{pl} = 405.6$ MPa.



TENSILE TEST - ASTM A370 / EN 10002

ELONGATION MEAS. APPARATUS

● Encoder

○ Extensometer A1

SPECIMEN DATA

Type of specimen ROUND

Weigth 0.946 Kg

Lt 600.0 mm

Mass 1.58 Kg/m

Area 200.8 mm²

Diameter 15.99 mm

☑ Proportional specimen

Lo 299.00 mm

Le 100.00 mm

OPTIONAL PARAMETER SELECTION

☐ Rt ☐ Ae ☐ Rp 0.20

☑ E ☐ At,Ag,Agt ☐ Su,Z

☐ Automatic PAUSE 0.00 %

0.0 kN

SPECIMEN DESCRIPTION

Client Students / GroupC+ D

Test Organisat. birzeit university

Test location ramallah

Test date 3

Date/time received 10/12/2019

Label report28

Steel type grade57

Sample Sample

☐ Position/direction of sample

☐ Plain ☑ Deformed

Machined: ☐ Yes ☑ No

NOTES AND TECHNICAL RESPONSIBILITY

Notes hgdjgdchmkgfc

Name Group c+ D

Position lab tech

Signature

CERTIFICATE IDENTIFICATION

Number test

Certificate date 10

fig(11): software tension test results

TENSILE TEST - ASTM A370 / EN 10002

STRESS STRAIN GRAPH

Fm (kN) 116.6

Rm (N/mm²) 580.5

ReH (N/mm²) 407.9

ReL (N/mm²) 405.6

A (%) 20.07

E (N/mm²) 12158.9

Lo (mm) 299.00

Lu (mm) 359.00

Elongation meas.apparatus: Encoder

fig(12): software stress-strain curve

- **Results & Conclusion**
  - Bend and re-bend

The bend re-bend test's result is positive, very small cracks and defects. (OK).

- Tension test:

σ_u = 580.5 MPa.

σ_Y = 407.9 MPa.

σ_{pl} = 405.6 MPa

E = 121.59 GPa.

ε_U = 20.07 %.

- The modulus of elasticity as obtained by the software is very low in comparison to that for the structural steel (200 GPa). Which means that this steel might not be valid for construction purposes. The result might be affected by many factors, for example if the bar is rusty it would be more brittle. Also, temperature has some effect on the result, if it is low the material tends to be stiffer, and vice versa.
- The ultimate strain of the bar is 20% which means that steel could be classified as a ductile material, since ASTM, classifies a material as ductile if its ultimate strain exceeds 7.07 %.
- The ultimate strength of the specimen is higher than the standard range specified by ASTM for A-36 steel which is (400-550).

There are many sources of error in the experiment, some of which are:

- Variable loading rate, since it is a manual lever.
- Poor placement of bar in the bending machine.
- Rusty steel.
- Temperature effect.
- Inaccurate measuring of bar length.
- Only one trial was made, which means that the results are not acceptable, regardless of whether they are right or wrong.

- **Refrences:**

1) Steel material properties:

https://www.steelconstruction.info/Steel_material_properties

2) Engineering ToolBox:

https://www.engineeringtoolbox.com/young-modulus-d_417.html

Table (2): bending and re-bending test standards for rollers and pillars

Diameter of iron rod		40	36	32	28	25	22	20	18	16	14	12	10	8	6
Diameter of axis	Bending	200	180	160	140	125	110	100	72	64	56	48	40	32	24
	Re-bending	400	360	320	250	200	176	160	125	100	80	63	50	40	32
Bending	The distance between the pillars	414	380	348	316	292	268	252	218	204	190	176	162	148	134
	The maximum distance between the pillars allowed	432	398	364	330	304.5	279	262	227	212	97	182	167	152	137
	The minimum distance between the pillars allowed	392	362	332	302	279.5	257	242	209	196	183	170	157	144	131