TENSILE TEST TO STUDY THE QUALITY OF REINFORCING STEEL BARS

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Abstract

In this research, samples of locally manufactured and imported reinforcing steel with different diameters 14 and 16 mm were studied by conducting tensile test, which is an important mechanical test to know the properties of mechanical materials and study their behaviour by under loading two samples of each type using a general tensile testing machine type (SHUMIDUZ –UH2000). The results obtained from this test were used to find a set of properties represented in the ultimate tensile strength (σ_{UTS}), yield strength or yield point (σ_y), yield strain(ϵ), and maximum strain (ϵ_{Max}), and there was a set of properties such as elastic modulus (E), Toughness modulus (T) and modulus of Resilience (U_r) that were mathematically calculated. The real stress and real strain for all samples were calculated too. The engineering stress and the engineering strain were presented by drawing the curves in order to show the difference. The results obtained from the tensile test showed that all samples were of steel reinforcement with protrusions of an average resistance (T30) where the yield stress values were 340-406 N/mm², and the tensile strength values were 574-673 N/mm² which conforms to the Libyan Standard No. 75 of 2013 for concrete reinforcing steel bars. The results also showed the convergence of local samples with the imported samples.

Keywords: Steel bars; Tensile test; tensile test machine; quality control; steel standards.

Introduction

Reinforcement or rebar is a common steel bar which is typically used in reinforced concrete structures. A wide range of rebar's in various shapes and sizes are available in Libya. They are equipped with ridges for better mechanical anchoring in concrete. Mild steel reinforcement are the most common because they are relatively inexpensive and yet offer acceptable material properties for many applications. Low carbon steel contains about 0.05 to 0.15% carbon and mild steel contains 0.16 to 0.29% carbon, so it is not brittle or ductile. Mild steel armor has relatively low

tensile strength, but it is cheap and malleable. The density of steel varies between 7.6 and 8.0 g / cm³ (Elert, 2004), and the modulus of elasticity is 210,000 MPa (ASTM A7, 1967). There are product standards that ensure that the armor manufactured around the world has the same physical, chemical, and mechanical properties regardless of its source. Appropriate mechanical tests are therefore required to determine whether the armor meets the published specifications and product quality. The tensile test is one of the most primary tests for engineering and provides precious information about a material and its properties. These properties can be used for the design and analysis of structures, as well as the development of new materials that are more suitable for a particular use Scribd (2020). In its simplest form, the tensile test is carried out by holding the opposite ends of a test element in the load frame of a testing machine. The machine exerts a tensile force which leads to progressive elongation and possible breakage of the tested piece. Force extension data is monitored and recorded during this process. When carried out correctly, the tensile test provides force-elongation data with which several important mechanical properties of a material can be measured.

These mechanical properties determined from the tensile test have been presented in (Jose, 2015) as follows:

- Elastic deformation properties, for example, the modulus of elasticity
- Yield strength and ultimate tensile strength
- Ductility properties, for example, elongation and reduction in area
- Strain-hardening characteristics

Material characteristics got from this test are used for quality control in production, for ranking the performance of structural materials, for evaluation of newly developed alloys, and for dealing with the static strength requirements of design (Edgar,2015). The present study has been conducted in the laboratories of mechanical properties in the Department of Minerals and Surface Protection of the Industrial Research Center of Tajoura - Libya. The work is based on the standards defined by the Libyan Standard No. 75 of 2013 for concrete reinforcing steel bars. The main objective was to conduct a tensile test to several home-made and imported samples in order to obtain a set of results which have been presented with graphical curves that help compare the results obtained and compare the quality of the local product with the other imported products. Imported products results can also be used to judge and control importing operations.

Materials and Methods

The researchers prepared eight samples of rebar with protrusions of two different diameters, according to the Libyan Standard Specification No. (74) for the year 2007 for tensile testing. Equal samples of 14mm, and 16mm diameter were selected from

both local and overseas steel manufacturing products. A tensile test for all samples was carried out and the results obtained were compared with the Libyan Standard No. (75) (2013) for steel bars for reinforcing concrete. A tensile test was carried out on the specimens using a general tensile testing machine type (SHUMIDUZ – UH2000). The tensile test helped in the determination of Yield Strength (σ_y) Ultimate Tensile Strength (σ_{UTS}), yield strain, Maximum strain, modulus of elasticity (E), modulus of resilience (U_r), modulus of toughness (T). In addition the real stress and real strain were widely compared with the engineering values.

Theory and Calculation

In a tensile test, the sample is subjected to a continuously increasing uniaxial tensile force while the elongation of the sample is simultaneously monitored. The geometric stress-strain curve is constructed from load and elongation measurements. The stress (σ) used in this curve is the average longitudinal stress in the tensile specimen. It is obtained by dividing the load (F) by the original area (A_0) of the cross- section of the specimen (Dieter, 1988).

$$\sigma = \frac{F}{A_0} \quad (1)$$

Since the samples are of a round section, the area is calculated as follows:

$$A_0 = \frac{\pi D^2}{4} \quad (2)$$

The strain (e) used for the geometric stress-strain curve is the average linear stress obtained by dividing the elongation of the sample scale length (ΔL) by its original length (L_0).

$$e = \frac{\Delta L}{L_0} \quad (3)$$

The most important mechanical properties obtained can be identified as follows:

- **Yield Strength (σ_y)**

$$\sigma_y = \frac{F_y}{A_0} \quad (4)$$

Where A_0 is the original cross - section area of the sample (mm^2), F_y is aloud of yield point (KN)

- **Ultimate Tensile Strength (σ_{UTS})**

$$\sigma_{UTS} = \frac{F_{Max}}{A_0} \quad (5)$$

Where F_{Max} is the Maximum load (KN)

▪ Modulus of Elasticity

Flexibility is a regular change in the dimensions of the metal as a result of its exposure to loads. This formation does not lead to any permanent change in the structure of the material. Rather, the atoms return to their original position with the demise of these loads.

Stress in the elastic region is directly proportional to strain through relationship:

$$\sigma = E e \quad (6)$$

This relationship is known as Hooke's law, where σ is the stress and e is the strain. The proportionality tab is called the elastic modulus (E), and it is measured in mega Pascal (Mpa) or Giga Pascal (Gpa) units, and its magnitude is determined by the slope of the straight line by the stress and strain curve as follows:

$$E = \frac{\Delta\sigma}{\Delta e} = \frac{\sigma_2 - \sigma_1}{e_2 - e_1} \quad (7)$$

Where: σ_1, σ_2 is the Stress value in the area of flexibility, e_1, e_2 is the Strain value in the elastic region.

▪ The Modulus of Resilience (U_r)

The Resilience modulus is defined as the area under the geometric stress-strain curve up to the yield point, which represents the maximum energy per unit volume that a sample can absorb flexibly. This energy can be recovered by stress relief.

$$U_r = \frac{\sigma_e^2}{2E} \quad (8)$$

Where: σ_e is the stress value at the limit of proportionality, E is the modulus of Elasticity

▪ The Modulus of Toughness (T)

The Toughness modulus is defined as the area under the entire stress-strain curve up to the fracture, which represents the maximum energy per unit volume that a sample can absorb before it completely fails due to the fracture. Unlike the modulus of Resilience, most of the energy cannot be recovered by decompression, due to the permanent plastic deformation of the material. The below equation (8) used for determining the material toughness (Favilla 2010).

$$T = \left(\frac{\sigma_y + \sigma_{UTS}}{2} \right) e_f \quad (9)$$

Where: σ_y is the Yield Strength, σ_{UTS} is the Ultimate Tensile Strength, e_f is the Strain value at a fraction

▪ Determining the True Stress and the True Strain

To Calculate true stress in the area of submission by relationship :

$$\sigma_{tru} = \sigma_{eng}(e + 1) \quad (10)$$

Where: σ_{eng} is the engineering stress, e is the engineering strain

As for the real stress after the occurrence of the neck (the loss zone), that is, after it is calculated by :

$$\sigma_{tru} = \sigma_{UTS}(e_{Max} + 1) \quad (11)$$

Where: σ_{UTS} is the Maximum tensile strength, e_{Max} is the Maximum strain

The true strain is calculated by :

$$\epsilon_{tru} = \ln(e + 1) \quad (12)$$

Where : e is the engineering Strain

Through these calculations, the relationship between real stress and real strain and their comparison with the geometric stress and geometric strain for all samples can be seen in the figure curves below.

Results and Discussion

The data obtained from tensile tests are summarized in Table (1). All tests were performed at room temperature, and the scale length of all samples was 200 mm. To preserve the credibility and the evaluation of the results in accordance with the policy of the laboratories of the Industrial Research Center, the trade names of the rebar used were coded as L₁, L₂, L₃ and L₄ for homemade samples, and as M₁, M₂, M₃ and M₄ for the imported samples. The results showed a great convergence of the obtained values for all locally manufactured and imported samples. When the results were compared with the Libyan Standard No. 75 of 2013 for steel bars for reinforcing concrete, it was found that the type of all samples was of a new reinforcement with protrusions of medium resistance, which was symbolized by the as (T30); where the yield stress values ranged between (340-406) N/mm², which conforms with Table (2). of the mechanical properties of steel bars of the above-mentioned specification.

Table (1): Tensile Test Results for All Steel Bar Samples.

Sample No.	Nominal Diameter(mm)	Tensile Test Results			
		$\sigma_y(N/mm^2)$	$\sigma_{UTS}(N/mm^2)$	e	e _{Max}
L ₁	14	340.072	574.298	5.67200	34.6940
L ₂		354.485	576.287	4.75600	32.9070
M ₁		392.447	625.576	4.72800	27.7160
M ₂		391.919	627.282	4.65800	28.9600
L ₃	16	347.219	566.337	4.21000	34.2060
L ₄		361.829	612.560	5.30900	28.5660
M ₃		406.622	670.285	4.44900	29.3370
M ₄		394.219	673.673	4.59000	30.2340

Table (2) shows the results of the elastic modulus for all samples, the higher the (E) values, the greater the stress required to cause the same strain, and this is what makes different materials exhibit different resistances when they are stressed. Therefore, Young's modulus expresses the resistance that the material exhibits to the occurrence of a strain when it is stressed. Unfortunately, unless we use an extensometer we will not be able to measure Young's modulus. The values obtained from the stress and strain curve for all samples ranged between (6724.5274-8864.1376 MPa), while the correct value of the elastic modulus of carbon steel is (2×10^5 MPa) . The difference is due to the stiffness of the testing machine itself.

Table (2): Shows The Results of the Elastic Modulus (E) for All Samples.

Sample No.	Nominal diameter(mm)	(E) (N/mm ²)
L	14	6724.5274
M		8357.1882
L	16	7480.225
M		8864.1376
All calculations represent the mean of two samples of each type.		

Table (3) shows the values obtained from the calculation of both the resilience factor characteristic and the modulus of toughness (T). These properties are used to measure the amount of energy absorbed by the metal before plastic deformation further more metamorphic in measuring the resilience factor.

Table (3): Shows the Results of the Modulus of Resilience and Modulus of Toughness, T(Mpa) for All Samples.

Sample No.	Nominal diameter(mm)	Ur (MPa)	T(MPa)
L	14	9.0370	175.1218
M		9.2026	150.2496
L	16	8.5704	167.3269
M		9.0463	184.9099
All calculations represent the mean of two samples of each type.			

True Stress and True Strain

Table (4): Shows the Values of the True Stress and the True Strain Measured at the Point of Yield, at the of Maximum Tensile Strength, and at the Point of Fracture.

Sample No.	Nominal Diameter(mm)	At yield point		At the maximum tensile strength		At the point of fracture	
		σ_{tru}	ϵ	σ_{tru}	ϵ	σ_{tru}	ϵ
L	14	365.5602	0.0507970	770.1345	0.291179	579.60	0.3220
M		344.8395	0.0458620	804.3540	0.249490	608.65	0.2585
L	16	371.5857	0.0464970	774.8444	0.272960	521.67	0.3038
M		418.7298	0.0442034	872.5742	0.260710	1008.75	0.2963

When comparing these results with the engineering stress, and strain, it is clearly seen that the real values are slightly higher than the engineering values. This basically refers to the real cross sections decrease while load is increased; this occurs rapidly after the yield point when the sample starts necking. Figures 1 and 2, show a comparison between the geometrics stress-strain curve and the true stress-strain curve for locally manufactured and imported rebar samples with a diameter of 14 mm whereas figure 3 and 4 show the geometrics stress-strain curve and the true stress-strain curve for local rebar samples and imported rebar samples with a diameter of 16 mm.

Figure (1): The True Stress Versus the True Strain, Along with the Engineering Stress, and Strain for Locally Manufactured Samples with a Diameter 14 mm.

Figure (2): The True Stress Versus the True Strain, Along with the Engineering Stress and Strain for Imported Rebar Samples with a Diameter of 14 mm.

Figure (3): The True Stress Versus the True Strain, Along with the Engineering Stress, and Strain for Locally Manufactured Samples with a Diameter of 16 mm.

Figure (4): The True Stress Versus the True Strain, Along with the Engineering Stress, and Strain for Imported Rebar Samples with a Diameter of 16 mm.

From these figures, it is clear that within the limits Material elasticity, the true stress and strain curve are almost identical to the geometric stress and strain curve; that is, until the elasticity limit or the point of submission is (True stress = Engineering stress), and then the true stress is greater than the engineering stress due to deficiency. The accident is in the cross-sectional area of the sample cross-section. From here we find that the stress-strain curve may give a true picture of the behaviour of the material under the influence of the stress necessary to increase the strain after the start of castration, as well as the reason that the stress of the fracture is less than the resistance of the maximum tension. So we find that the stress-strain

curve has disappeared from this decrease, and it has become normal and has followed acceptable behaviour.

Conclusions

The tensile test helped to provide a set of the mechanical properties of the samples which included their resistance, ductility and durability. The results of the tensile test also showed that all samples from rebar were with protrusions of medium resistance (T.30) according to the Libyan Standard No. 75 of 2013 for concrete reinforcing steel bars. Hence, all the samples were in compliance with the limits of the mentioned standard; this is an evidence of the good quality of the local product that is no less than the quality of the imported products.

Nomenclature

A	Effective cross-sectional area [mm ²]	e_r	Strain value at a fraction
L	Length of the bar [m]	σ_{eng}	Engineering stress[MPa]
L₀	Gauge length [mm]	σ_{tru}	True stress[MPa]
D	Nominal diameter of the test specimen [mm]	e	Engineering strain
σ_y	Yield Strength [MPa]	ε	True strain
F_y	Load of yield point [KN]	E	Elastic modulus [N/mm ²]
σ_{UTS}	Ultimate Tensile Strength [MPa]	T	Toughness modulus [MPa]
F_{Max}	Maximum load [KN]	U_r	Modulus of Resilience [MPa]

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