Evaluation of Mechanical Properties of Reinforcement Steel Bars: Case Study On Construction Works In Aden - Yemen

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Evaluation of Mechanical Properties of Reinforcement Steel Bars: Case Study on Construction Works in Aden - Yemen

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Abstract— Reinforcing steel bars are one of the major construction materials that are used for most of the engineering applications and construction purposes. However, steel reinforcing bars are used daily in the construction of various buildings in Yemen, but their suitability has not yet been confirmed. This study is aimed at assessing the mechanical properties of 10, 12, 14, 16, 18, and 20mm sizes of imported and locally reinforcing steel bars used in building construction in Aden, Yemen. Mechanical properties include ultimate tensile strength and yield strength of the steel specimens that were determined and also compared to the corresponding limit as defined in the British Standard BS4449:1997. The tensile test was performed in the Material Science Lab in the Faculty of Engineering at the University of Aden, Yemen, using a tensile testing machine (SM1001). The findings show that the yield tensile strength values of 10, 12, 14, 18, and 20mm bar sizes are ranging from 318 to 444.8, which is lower than the BS 4449 specification of 460, except the 16 mm bar sizes, which are higher and range from 463.62 to 466.36. For ultimate tensile strength tested, only 16 mm bar sizes are conforming to the standard BS4449:1997 specification of 600, which are ranging from 602.12 to 637. This shows that the failure rate is very high among the tested samples. Therefore, it is recommended to critically evaluate the mechanical properties of local and imported reinforcing bars before using them in construction works in the country to achieve optimum safety.

Keywords— Reinforced Steel Bars, Tension Tests, Stress Strain Curve, BS Standard, Mechanical Properties.

I. Introduction

Critical evaluation of material properties must be carried out before being used in construction work. This is especially important in avoiding the failure parameters of the structure under conditions of service [1]. Steel is one of the major construction materials that is used for most of the engineering applications and construction purposes [2]. The mechanical properties of reinforcing steel bars must conform to the quality specifications and codes standards of practice on which the designs are based for effective utilization [3, 4, 5]. The carbon content greatly affects the mechanical properties of materials as it increases with increasing carbon content [6]. The tensile strength of materials improves with high carbon content, while low carbon content produces ductile material with low strength [7]. The main sources of reinforcing steel available in Yemen's construction works are local and international. The reinforcing steel used in the local construction works in Yemen is purchased without determining their actual properties. The steel is also used in buildings without any testing to ensure its adequacy and conformity to actual specifications. [8, 9]. The local and imported reinforcing steel in Yemen must have their own quality test certificate, and regulatory authorities must conduct periodic inspections to ensure that they conform to the standard specifications [10]. Hence, this study is aimed at assessing the mechanical properties, including ultimate tensile strength and yield tensile strength of 10 mm, 12 mm, 14 mm, 16 mm, 18 mm, and 20 mm reinforced steel, which was randomly selected from various construction sites in Aden, Yemen. The method executed to assess the mechanical properties of reinforcing steel bars was by carrying out a tensile strength test on the specimens of reinforcing steel using a tensile testing machine and comparing the results of the tested samples with the British standard code BS4449:1997 as well as **determining** their convenience for purpose building construction.

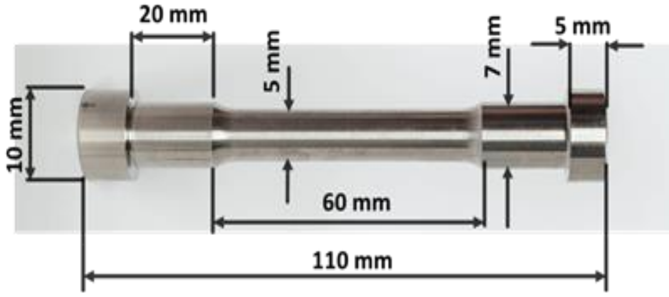
II. Materials and Methods

A. Sample Collection and Preparation

The reinforcing steel samples in this study were selected randomly from different building construction sites in Aden, Yemen. Three samples each of 10, 12, 14, 16, 18 and 20 mm reinforcing steel bars were randomly chosen for this study is only grade 60 is shown in **Figure 1 (a)**. A total of 18 samples were collected from different building construction sites. The steel bar specimens are machined into standard initializers using a lathe machine in the desired shape and size according to the BS4449:1997 standards indicated in **Figure 1 (b)**. A tensile strength test was carried out on these specimens and compared with BS 4449:1997 specifications [11], and after fracture, the ultimate tensile strength and yield tensile strength were calculated using the following equation.

$$\sigma = \frac{P}{A} \qquad (1)$$

Where, σ is the ultimate and yield tensile strength (MN/mm2)), is the applied load (MN), original cross sectional area of steel bar (mm2).



(a) **(b)**

Fig. 1. (a) Some of the samples before standardization; (b) Tensile test specimen from the reinforcing steel

B. Mechanical Property Test

The determined of the mechanical properties include ultimate tensile strength and yield tensile strength of reinforcing steel were carrying out by tensile strength test on the specimens of reinforcing steel using a Tensile Testing Machine (SM1001), works with Versatile Data Acquisition System (VDAS) with maximum load of 20 kN is shown in **Figure 2**.

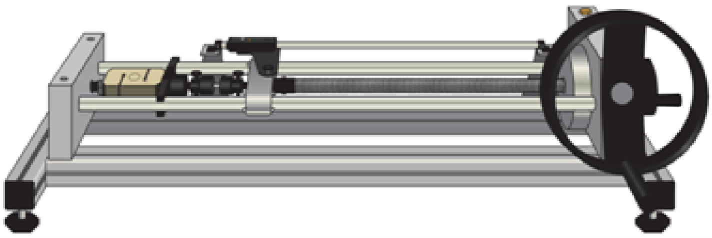


Fig. 2. Tensile Testing Machine

In this study, the mechanical test was conducted at the Material Science Lab in Faculty of Engineering - University of Aden - Yemen. The test was carried according to International British standard code (BS4449:1997) [11]. The setup of experimental is shown in **Figure 3**.

(a) **(b)**

Fig. 3. (a) Tensile test specimen in the tensile testing machine, (b) Specimens after tensile tests

III. Results and Discussion

The method executed to assess the mechanical properties includes yield tensile strength and ultimate tensile strength of reinforcing steel bars was by comparing the results of the tested samples with the British standard code BS4449:1997. The ultimate tensile strength and yield tensile strength test results on the 18 steel samples of 10, 12, 14, 16, 18 and 20 mm bars sizes of reinforcing steel are presented in **Figure 4, Figure 5, Table 1 and Table 2**. In addition, **Figures 6 to 12** show the stress-strain curves measured of different diameter sizes of reinforcing steel bars.

A. Yield Stress

Figure 4 and Table 1 show a comparison between the yield tensile strength of the tested reinforcing steel bar specimens with the BS4449:1997. This shows that the failure rate is very high among the tested samples. With about 84% of the tested samples less than the code value of 460 N/mm² specified in the BS4449:1997 standard [11]. The tested samples of reinforcing steel bars recorded the lower yield tensile strength compared with the BS4449:1997, except the 16 mm reinforcing steel bar sizes. The tested samples of 16 mm diameter bar sizes recorded the highest yield tensile strength values compared with the BS4449:1997, while the lowest yield tensile strength values were obtained for 10 mm, 12

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mm, 14 mm, 18 mm, and 20 mm bar sizes. The yield tensile strength values for 16 mm bars range from 463.62 N/mm² to 466.36 N/mm², which is above and satisfies the code values set by the BS4449:1997 specification of 460 N/mm². The yield tensile strength values for 10 mm, 12 mm, 14 mm, 18 mm, and 20 mm bars range from 318 N/mm² to 444.8 N/mm², which is lower and unsatisfactory than the code values set by the BS4449:1997 specification of 460 N/mm². This is perhaps an indication that the 16 mm bars have more carbon content than the 10 mm, 12 mm, 14 mm, 18 mm, and 20 mm bars, as increased percent carbon contributes to increased yield tensile strength in products of the reinforcing steel [12, 13].

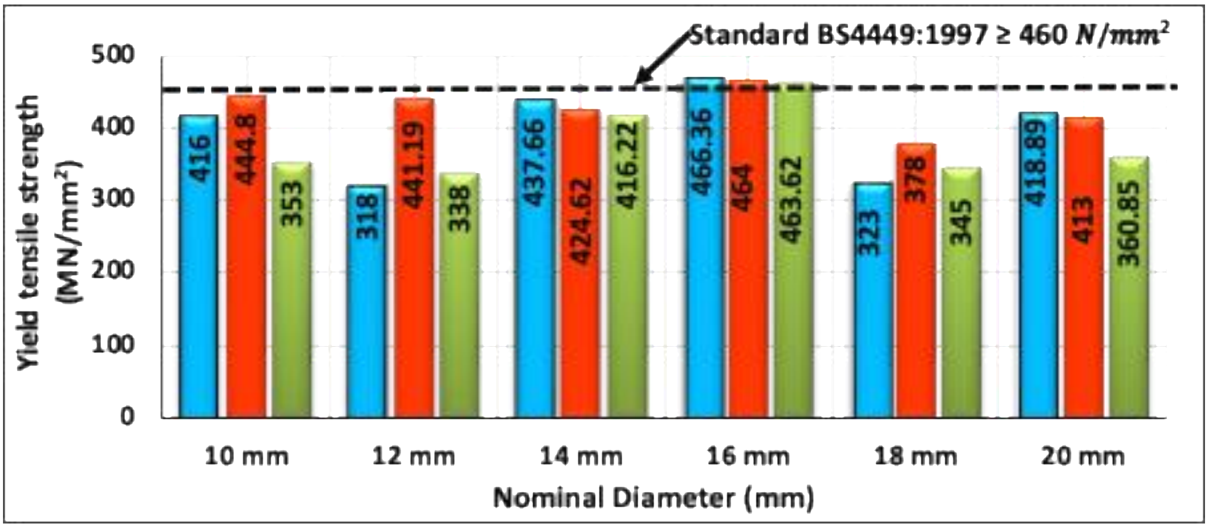

Fig. 4. Yield tensile strength of reinforcement bars compared with BS4449:1997

Table 1: Yield tensile strength of reinforcement bars compared with BS4449:1997

Bar Diameter (mm)	Specimens	Yield tensile strength (MN/mm^2)	Standard BS4449:1997 [11]	Difference	% difference $= \frac{St.-Meas.}{Meas.}$	Remarks
10	Specimen 1	416	≥ 460	-44	-10.6%	Below => Unsatisfactory
	Specimen 2	444.8	≥ 460	-15.2	-3.4%	Below => Unsatisfactory
	Specimen 3	353	≥ 460	-107	-30.3%	Below => Unsatisfactory
12	Specimen 4	318	≥ 460	-142	-44.7%	Below => Unsatisfactory
	Specimen 5	441.19	≥ 460	-18.81	-4.3%	Below => Unsatisfactory
	Specimen 6	338	≥ 460	-122	-36.1%	Below => Unsatisfactory
14	Specimen 7	437.66	≥ 460	-22.34	-5.1%	Below => Unsatisfactory
	Specimen 8	424.62	≥ 460	-35.38	-8.3%	Below => Unsatisfactory
	Specimen 9	416.22	≥ 460	-43.78	-10.5%	Below => Unsatisfactory
16	Specimen 10	466.36	≥ 460	6.36	1.4%	Above => Satisfactory
	Specimen 11	464	≥ 460	4	0.9%	Above => Satisfactory
	Specimen 12	463.62	≥ 460	3.62	0.8%	Above => Satisfactory
18	Specimen 13	323	≥ 460	-137	-42.4%	Below => Unsatisfactory
	Specimen 14	378	≥ 460	-82	-21.7%	Below => Unsatisfactory
	Specimen 15	345	≥ 460	-115	-33.3%	Below => Unsatisfactory
20	Specimen 16	418.89	≥ 460	-41.11	-9.8%	Below => Unsatisfactory
	Specimen 17	413	≥ 460	-47	-11.4%	Below => Unsatisfactory
	Specimen 18	360.85	≥ 460	-99.15	-27.5%	Below => Unsatisfactory

B. Ultimate Tensile Strength

Figure 5 and **Table 2** show a comparison between the ultimate tensile strength results of the tested reinforcing steel specimens with the BS4449:1997. From the results, it has been observed that 84% of the samples tested less than the characteristic code value of 600 N/mm² specified in the BS4449:1997 [11] standard. The tested samples of reinforcing steel bars recorded the lower yield tensile strength compared with the BS4449:1997, except the 16 mm reinforcing steel bar sizes. The ultimate tensile strength values for 16 mm bars range from 602.12 N/mm² to 637 N/mm², which is above the specification range value of 600

N/mm² set by BS4449:1997. The ultimate tensile strength values of 10 mm, 12 mm, 14 mm, 18 mm, and 20 mm bars range from 493 N/mm² to 596.85 N/mm². These values are lower than the standard limit of 460 N/mm² set by BS4449:1997. This may be an indication that the 16 mm bars contain more carbon than the 10 mm, 12 mm, 14 mm, 18 mm, and 20 mm bars, as increased percent carbon contributes to increased ultimate tensile strength in products reinforcing steel [12, 13].

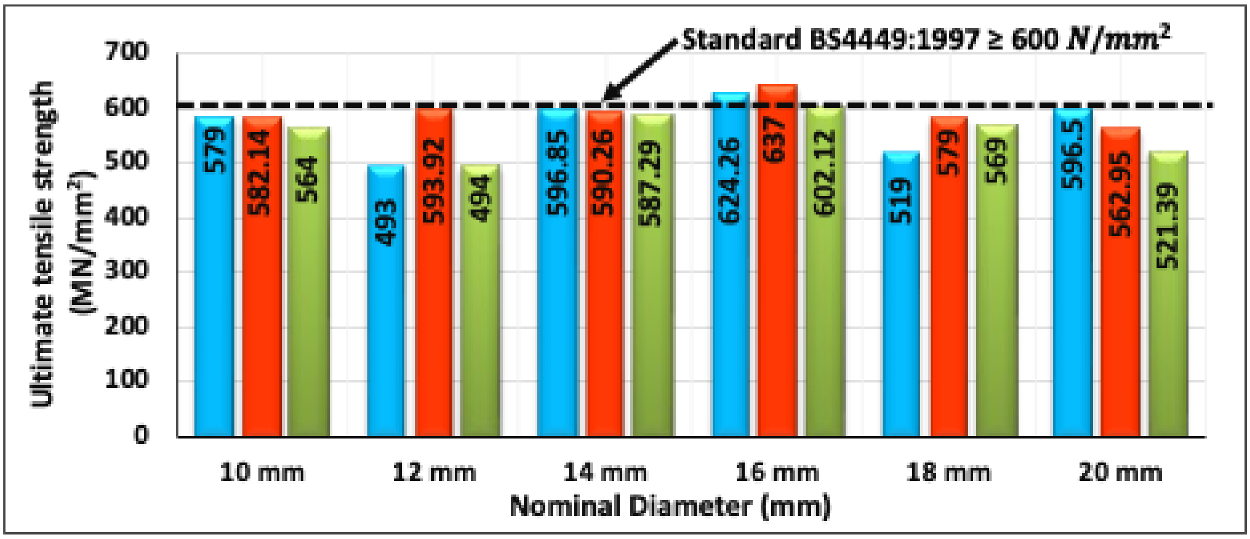

Fig. 5. Ultimate tensile strength of reinforcement bars compared with BS4449:1997

Table 2. Ultimate tensile strength of reinforcement bars compared with BS4449:1997

Bar Diameter (mm)	Specimens	Ultimate tensile strength (MN/mm2)	Standard BS4449:1997 [11]	Difference	% Difference $= \frac{St.-Meas.}{Meas.}$	Remarks
10	Specimen 1	579	≥ 600	-21	-3.6%	Below => Unsatisfactory
	Specimen 2	582.14	≥ 600	-17.86	-3.1%	Below => Unsatisfactory
	Specimen 3	564	≥ 600	-36	-6.4%	Below => Unsatisfactory
12	Specimen 4	493	≥ 600	-107	-21.7%	Below => Unsatisfactory
	Specimen 5	593.92	≥ 600	-6.08	-1.0%	Below => Unsatisfactory
	Specimen 6	494	≥ 600	-106	-21.5%	Below => Unsatisfactory
14	Specimen 7	596.85	≥ 600	-3.15	-0.5%	Below => Unsatisfactory
	Specimen 8	590.26	≥ 600	-9.74	-1.7%	Below => Unsatisfactory
	Specimen 9	587.29	≥ 600	-12.71	-2.2%	Below => Unsatisfactory
16	Specimen 10	624.26	≥ 600	24.26	3.9%	Above => Satisfactory
	Specimen 11	637	≥ 600	37	5.8%	Above => Satisfactory
	Specimen 12	602.12	≥ 600	2.12	0.4%	Above => Satisfactory
18	Specimen 13	519	≥ 600	-81	-15.6%	Below => Unsatisfactory
	Specimen 14	579	≥ 600	-21	-3.6%	Below => Unsatisfactory
	Specimen 15	596.5	≥ 600	-3.5	-0.6%	Below => Unsatisfactory
20	Specimen 16	594.96	≥ 600	-5.04	-0.8%	Below => Unsatisfactory
	Specimen 17	562.95	≥ 600	-37.05	-6.6%	Below => Unsatisfactory
	Specimen 18	521.39	≥ 600	-78.61	-15.1%	Below => Unsatisfactory

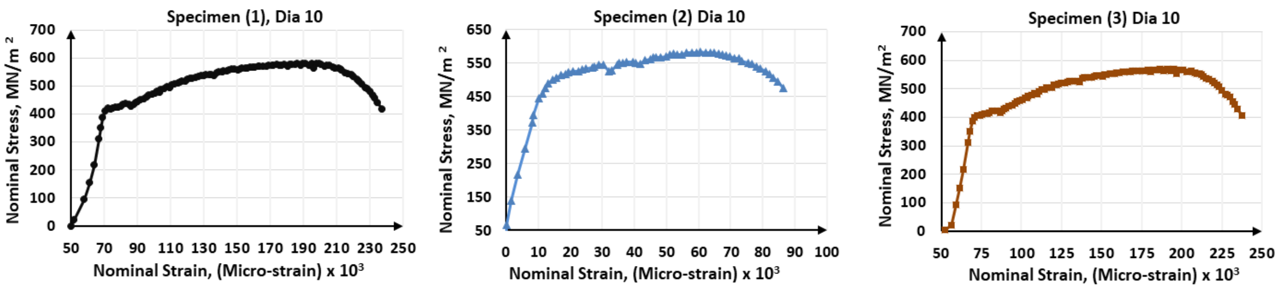

Fig. 6. Stress – strain curve for 10 mm sizes of the reinforcing steel specimens

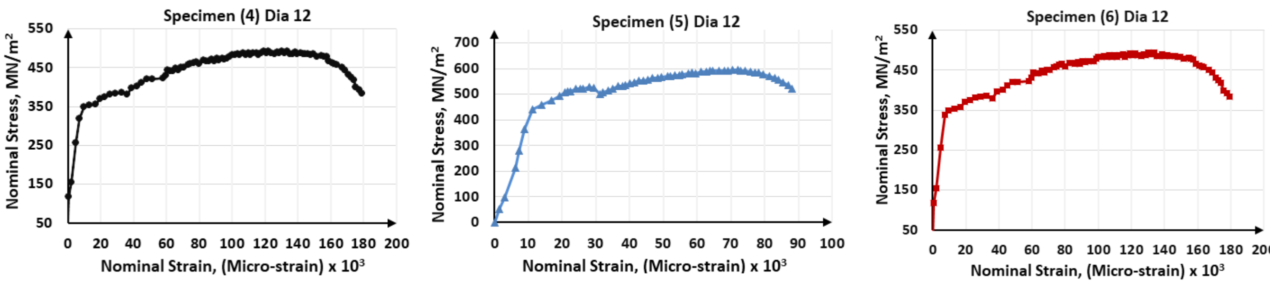

Fig. 7. Stress – strain curve for 12 mm sizes of the reinforcing steel specimens

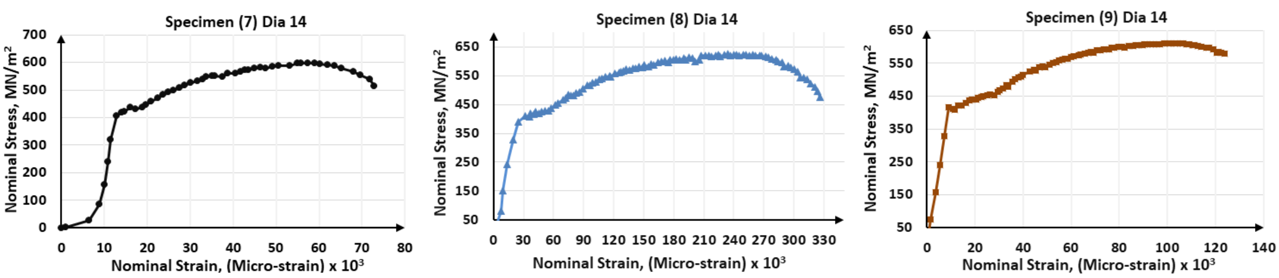

Fig. 8. Stress – strain curve for 14 mm sizes of the reinforcing steel specimens

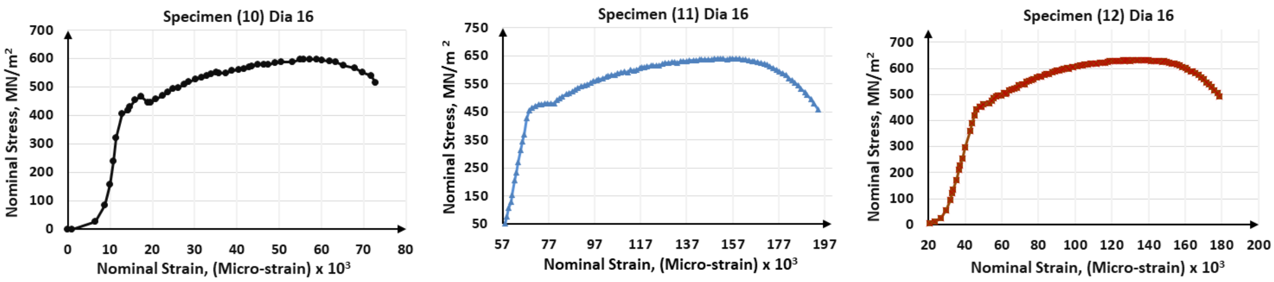

Fig. 9. Stress – strain curve for 16 mm sizes of the reinforcing steel specimens

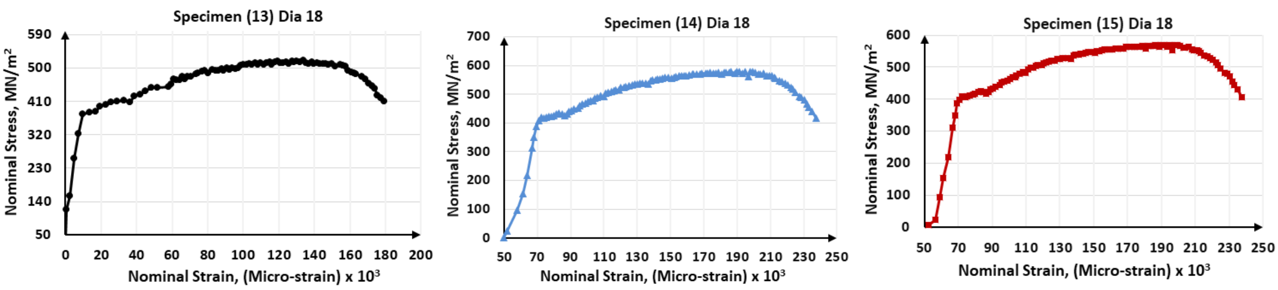

Fig. 10. Stress – strain curve for 18 mm sizes of the reinforcing steel specimens

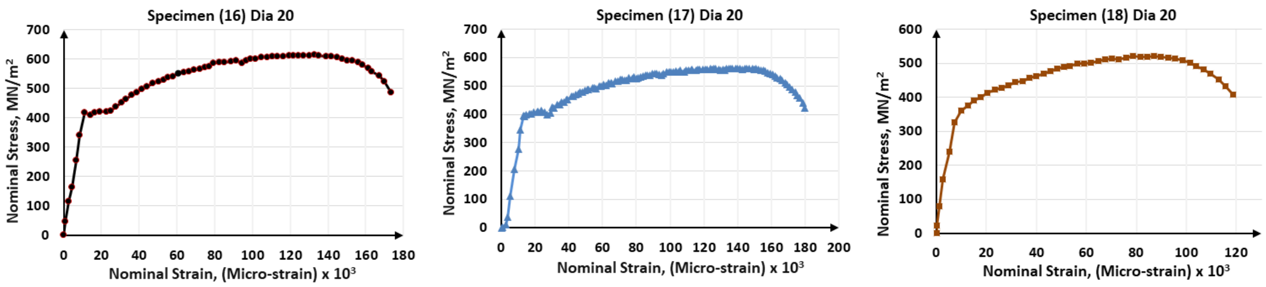

Fig. 11. Stress – strain curve for 20 mm sizes of the reinforcing steel specimens

IV. Conclusions

This study provided results of a mechanical test that aimed to assess the mechanical properties of 10, 12, 14, 16, 18, and 20 mm diameter sizes of imported and locally reinforcing steel bars used in building construction in Aden, Yemen. Mechanical properties include yield tensile strength and ultimate tensile strength of the steel specimens were determined and also compared with the corresponding limit as specified in the British standard BS4449:1997. The results show that the failure rate is very high among the tested samples. With about 84% of the tested samples falling below the code value of the BS4449:1997. The values of the yield tensile strength for 10 mm, 12 mm, 14 mm, 18 mm, and 20 mm are ranging from 318 N/mm^2 to 444.8 N/mm^2, which is less than the standard BS4449:1997, while only sample 16 mm bars, the yield tensile strength of which is ranging from 463.62 N/mm^2 to 466.36 N/mm^2, are conforming to standard BS4449:1997 prescription 460 N/mm^2. For ultimate tensile strength tested, only 16 mm bars are conforming to the standard BS4449:1997 specification of 600 N/mm^2, which are ranging from 602.12 N/mm^2 to 637 N/mm^2. The values of the ultimate tensile strength of the 10 mm, 12 mm, 14 mm, 18 mm, and 20 mm bars are ranging from 493 N/mm^2 to 596.85 N/mm^2, which is less than the standard BS4449:1997 prescription of 600 N/mm^2. It was therefore recommended to critically evaluate the mechanical properties of local and imported reinforcing bars before using them in construction works in the country to achieve optimum safety. The local and imported reinforcing steel in Yemen must have its own quality test certificate, and regulatory authorities must conduct periodic inspections to ensure that they conform to the standard specifications.

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