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Study of Elastic Properties of Reinforcing Steel Bars

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ABSTRACT

Reinforcing steel bars (rebars) are used for reinforcing concrete. The elastic properties of rebars affect the load bearing capacity of a structure. In this research, the ultimate strength, yield strength, percentage elongation at fracture, mass per meter length and stress ratio of four popular brands of steel rebars (whose names are not permitted to be disclosed) having diameters 10 mm, 12 mm, 16 mm and 20 mm were compared and contrasted against each brand under investigation. The research was conducted based upon the standards established by the SLS 375, SLS 978 and BS 4447 at the Material Research Laboratories of Sri Lanka Standards Institute and National Building Research Organization, Sri Lanka.

1. INTRODUCTION

A rebar, or reinforcing bar, is a common steel bar, and is generally used in reinforced concrete structures. A wide range of rebars with different shapes and sizes are available in Sri Lanka and is given ridges for better mechanical anchoring into the concrete. Mild steel rebars are the most common, as its price is relatively low while it provides material properties that are acceptable for many applications. Low carbon steel contains approximately 0.05–0.15% carbon and mild steel contains 0.16–0.29% carbon, therefore it is neither brittle nor ductile. Mild steel rebars have a relatively low tensile strength, but it is cheap and malleable. The density of steel is varies from 7.6 to 8.0 g/cm^3 [1] and the Young's modulus is 210,000 MPa [2]. Concrete is reinforced with slender cylindrical steel rebars where the rebars are placed at structural locations where bending forces will produce internal tensile stresses and to transfer these forces from the concrete to the steel reinforcement, a good shear bond must be developed between the concrete and steel and for this reason rebars are manufactured with small surface deformations to enhance shear transfer [3].

The mechanical properties of steel rebars affect the load bearing capacity of a particular structure. The properties most commonly used for rebars as a basis for specification and design are the specified minimum yield strength and the specified minimum ultimate strength, both obtained from tensile tests on specimens of steel rebars. Rebars can be either smooth or deformed and they are produced by hot rolling or cold working processes [3]. Work hardening, strain hardening, or cold work is the strengthening of a material by, plastic deformation. Any material with a reasonably high melting point such as metals and alloys can be strengthened in this fashion. Metal alloys not agreeable to heat treatment, including low-carbon steel, are often work-hardened. Thus, cold working generally results in higher yield strength as a result of the increased number of dislocations and a decrease in ductility [4]. Hot rolling is a hot working metalworking process where large pieces of metal, such as slabs or billets, are heated above their recrystallization temperature and then deformed between rollers to form thinner cross sections [5].

The present study was conducted at the Material Research Laboratories of Sri Lanka Standards Institute (SLSI) and National Building Research Organization (NBRO). The work was based upon the standards established by the SLS 375, SLS 978 and BS 4447 [6,7]. The main objective was to analyze the ultimate strength, yield strength, percentage elongation at fracture, mass per meter length and stress ratio of four brands of steel rebars, with different sizes in diameter available in Sri Lanka.

2. METHODOLOGY AND IMPLEMENTATION

2.1 Measurements

The cross sectional area and mass of the bars was calculated on the basis that steel has a mass of 0.00785 kilograms per square millimetres per meter run. The effective cross sectional area of a substantially uniform length of rebar was determined by weighing and measuring a length of not less than 0.5 m and was calculated as follows [6]:

$$A = \frac{M}{0.00785L} \qquad \textbf{(1)}$$

where, A is the effective cross sectional area (in square millimetres) M is the mass of the bar (in kilograms) and L is the length of the bar (in meters)

The gauge length marked on each test specimen was calculated as follows [7]:

$$L_0 = 5.65\sqrt{A} \qquad \textbf{(2)}$$

But in practice, the initial gauge length was measured by the following approximated equation due to simplicity. $L_0 = 5D$, where, L_0 is the gauge length on the test piece in millimetres and D is the nominal diameter of the test specimen (in millimetres).

The length of each test specimen was to be at least 600 mm or 20 times the nominal diameter, which ever was the greatest. But in practice the length was taken to be approximately equal to 1000 mm since the brand mark of the manufacturer was printed on the rebar for every length of 1000 mm.

Prior to the test, equidistant marks were in-scribed on the test specimen, where the distance between 2 successive marks was equal to a sub multiple of the initial gauge length L_0'. The measurement of the final gauge length after fracture L_u' was made on the longest broken part of the test specimen.

The percentage non-proportional elongation (A_G) at maximum force was calculated based on the following formula [6].

$$A_G = \frac{L_u' - L_0'}{L_0'} \text{ x } 100\% \qquad \textbf{(3)}$$

2.2 Procedure

Tensile tests were carried out on four leading brands of rebars found in Sri Lanka. Before the tests, all bars were inspected for defects, e.g. seams, porosity, segregation, non-metallic inclusions, etc., which might adversely affected the tensile properties.

Specimens were tested in air under axial tensile loading, using tapered grips and a suitable gripping medium.

The tests were carried out on straight rebars under load control and stresses were calculated on the nominal area. The ultimate strength (R_M), yield strength (R_E), percentage elongation at fracture (A_T), mass per meter length (M_L) and stress ratio (R_M/R_E) were determined based on the methods described in SLS 978 and BS4449. The upper yield strength was determined for rebars showing a defined yield point. If this was not applicable, the 0.2 percent proof stress ($R_{p0.2}$) was determined.

3. RESULTS AND DISCUSSION

The results obtained from the tensile tests conducted at the Materials Testing Laboratory at NBRO, Sri Lanka. The data obtained from the tensile tests are summarized in Table 1. All tests were carried out at temperature 31 ± 1 °C. Since the names of brands of steel rebars used are not permitted to be disclosed, they are arbitrary labelled as A, B, C, and D.

Table 1: Tensile properties of four brands labelled as A, B, C and D rebars

Brand	Nominal Diameter (mm)	R_E x 10^2 (MPa)	R_M x 10^2 (MPa)	A_T x 10 (%)	M_L x 10^{-1} (kg m^{-1})	R_M/R_E
A	10	5.87 ± 0.07	6.82 ± 0.03	1.380 ± 0.002	5.87 ± 0.01	1.16 ± 0.02
	12	6.23 ± 0.23	7.29 ± 0.28	1.211 ± 0.003	8.71 ± 0.03	1.17 ± 0.03
	16	4.34 ± 0.06	5.32 ± 0.07	1.979 ± 0.002	15.42 ± 0.01	1.23 ± 0.02
	20	5.38 ± 0.09	6.45 ± 0.04	1.373 ± 0.002	24.68 ± 0.03	1.20 ± 0.02
B	10	5.29 ± 0.20	6.48 ± 0.23	1.830 ± 0.003	6.03 ± 0.02	1.23 ± 0.03
	12	5.45 ± 0.28	6.58 ± 0.45	1.678 ± 0.002	8.88 ± 0.06	1.21 ± 0.02
	16	5.42 ± 0.06	6.41 ± 0.12	1.413 ± 0.001	15.62 ± 0.04	1.18 ± 0.01
	20	5.5 ± 0.1	6.32 ± 0.08	1.593 ± 0.001	24.5 ± 0.1	1.15 ± 0.01
C	10	5.44 ± 0. 03	6.60 ± 0.08	1.507 ± 0.001	5.99 ± 0.01	1.214 ± 0.01
	12	4.94 ± 0.06	4.95 ± 0.01	1.606 ± 0.001	8.92 ± 0.01	1.21 ± 0.01
	16	5.23 ± 0.05	6.28 ± 0.07	1.471 ± 0.001	15.76 ± 0.02	1.18 ± 0.01
	20	5.4 ± 0.1	6.64 ± 0.01	1.483 ± 0.002	24.41 ± 0.03	1.23 ± 0.02
D	10	5.19 ± 0.05	5.76 ± 0.02	1.893 ± 0.001	5.89 ± 0.01	1.11 ± 0.01
	12	4.91 ± 0.05	4.92 ± 0.05	2.100 ± 0.001	8.63 ± 0.01	1.11 ± 0.01
	16	4.97 ± 0.01	5.961 ± 0.002	1.2542 ± 0.0003	15.7 ± 0.1	1.200 ± 0.003
	20	4.72 ± 0.01	5.69 ± 0.05	1.430 ± 0.001	24.4 ± 0.1	1.20 ± 0.01

Based on the results obtained from the tensile tests, the following diagrams summarizing each characteristic tensile property associated with the different brands of rebars under investigation were sketched.

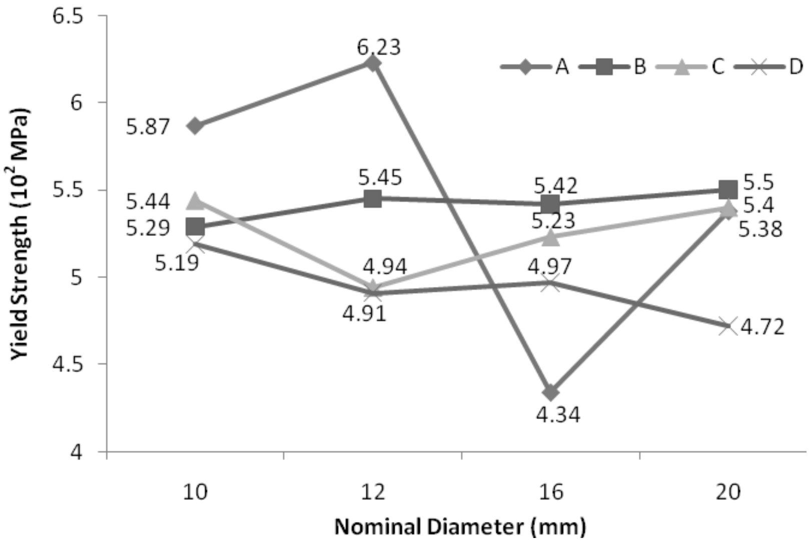

Figure 1: The yield strength vs. nominal diameter of different brands of rebars

From Figure 1, it can be observed that for 10 mm and 12 mm rebars brand A has the maximum yield strength, whereas for 16 mm and 20 mm rebars, the brand B has the uppermost value. For 20 mm rebars, brand B has the maximum yield strength. The reason for brand A demonstrating highest yield values for 10 mm and 12 mm rebars and brand B for 16 mm and 20 mm rebars is due to the fact that both brands of rebars are manufactured by work hardening (cold work) which results in higher yield strength.

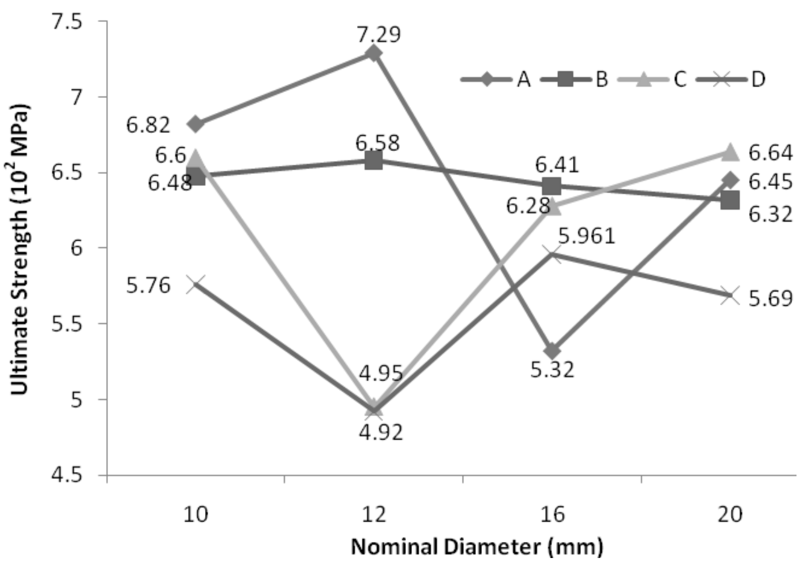

Figure 2: The ultimate strength vs. nominal diameter of different brands of rebars

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From Figure 2, considering the highest ultimate strength, it can be observed that brand A has highest value for 10 mm and 12 mm rebars, Brand B has the highest value for 16 mm rebars and brand C tops the 20 mm category.

Since the rebars of brands A and B are manufactured by work hardening, brand A demonstrates higher yield values for 10 mm and 12 mm rebars and brand B for 16 mm rebars. However, as shown in Figures 1 and 2, it can be observed that there is a sharp decline in the ultimate strength distribution for brand A rebars of 16 mm diameter. One of the main reasons why this has occurred might be due to the fact that brand A rebars of 16 mm diameter demonstrated an unusual increase in elongation for 16 mm rebars as seen in Figure 3. But when the values of R_E, R_M and A_T for 10 mm and 12 mm rebars of brand A are compared, it can be observed that when the R_E and R_M values are high, the elongation is the lowest in their respective categories.

From Figure 3, considering the elongation, the brand D has the highest value for 10 mm and 12 mm rebars whereas the brand A has the maximum value for 16 mm rebars and brand B has the top most value for 20 mm rebars.

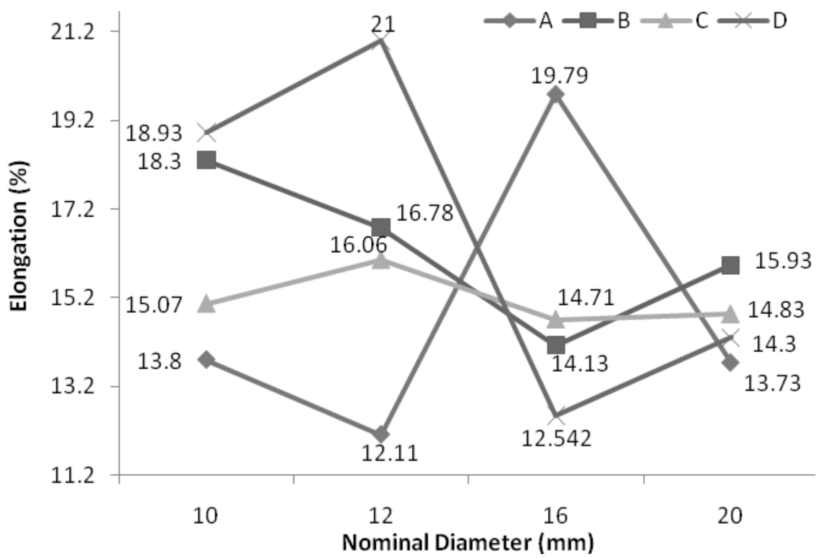

Figure 3: The elongation vs. nominal diameter of different brands of rebars

When Figures 1 and 2 are studied closely, it can be seen that brand D demonstrate the lowest values for R_E and R_M for 10 mm and 12 mm rebars and the same brand has the highest values recorded for elongation for the same range. Furthermore, the brand A demonstrate the lowest values for R_E and R_M for 16 mm rebars. Even though the brand D demonstrates the lowest values for R_E and R_M the value of A_T is not the lowest.

Based on Figure 4, all four brands have nearly the same values for mass per meter length for all rebars investigated. Also, it can be observed that as the nominal diameter increases from 10 mm to 20 mm, so does mass per meter length. This is because as the diameter increases the volume and hence the mass of the rebars increase for a given length.

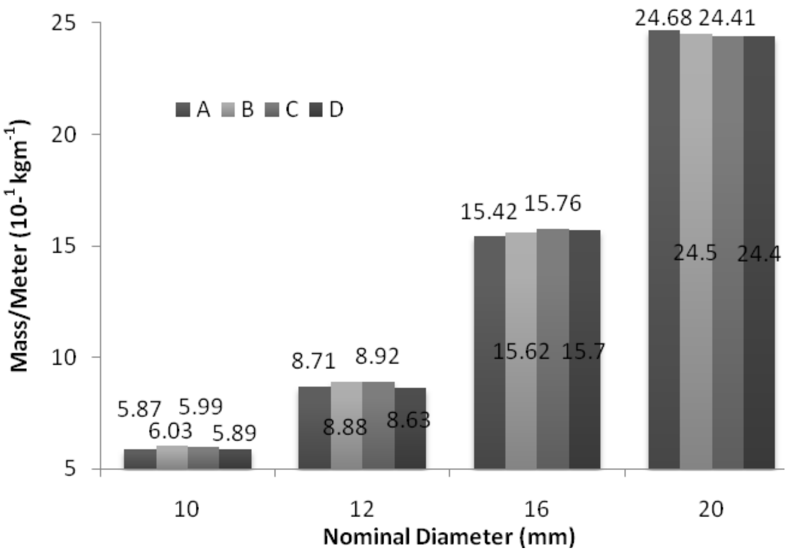

Figure 4: The mass per meter length vs. nominal diameter of different brands of rebars

Even though the mass per meter length values for each brand of rebar are virtually similar, the values for R_E, R_M and A_T and R_M/R_E of all the brands does not demonstrate the same observation. The root cause for these deviations in the tensile properties is due to the manufacturing process involved in the production of each brand of rebar, where brands A, B and D are manufactured by work hardening and brand C rebars are manufactured by hot rolling.

From Figure 5, it can be observed that brand B has the highest value for 10 mm rebars and for 12 mm rebars brand C coincides with brand B with the same value for stress ratio, in addition to having the highest value 20 mm rebars as well. Brand A only demonstrates the highest value for stress ratio for 16 mm rebars even though the values for R_E and R_M for 10 mm and 12 mm rebars were higher.

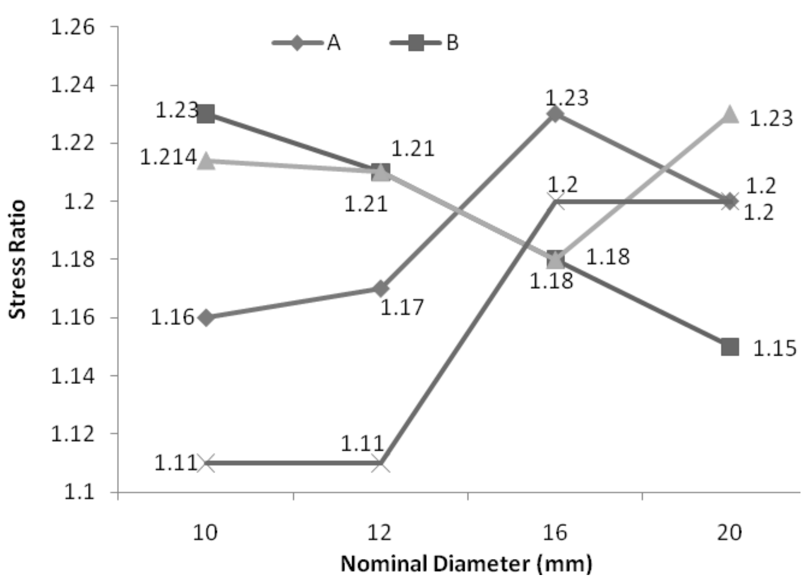

Figure 5: The stress ratio vs. nominal diameter of different brands of rebars

When closely observing brand C, it can be seen that there are no irregularities in the tensile properties as demonstrated in Figures 1 - 5. This is because brand C rebars are manufactured by hot rolling. Even though hot rolling does not manipulate the tensile properties of steel, it alters the geometry of the crystal structure so that the crystals are arranged in an equiaxed (axes of approximately the same dimensions) structure. Therefore, this has led to the consistent behaviour of the rebars belonging to brand C, even though there is a variation found in R_M based on Figure 3. This is because, when the steel rebars are manufactured by work hardening, it leads to the material being less ductile, i.e. the material becomes more brittle. And as the ductility reduces, ultimate strength of the material increases, which results in higher R_M values for brands A and B.

4. CONCLUSION

The results derived from the tensile tests are summarized in Table 2. It can be deduced that if high tensile (yield and ultimate) strengths are required brand A is to be the preferred choice for rebars of 10 mm and 12 mm and brand B should be the preferred choice for rebars with a nominal diameter of 16 mm. and by considering the rankings designated in the above table, brand A and brand B demonstrates equal distribution.

Table 2: The ranked results of tensile properties of rebars

Parameter	10 mm	12 mm	16 mm	20 mm
R_E	A	A	B	B
R_M	A	A	B	C
A_T	B	D	A	B
M_L	B	C	C	A
R_M/ R_E	B	C	A	C

The decision of choosing which brand for construction will solely depend on the requirements outlined by the designers to construct the strongest building structures, while maintaining the lowest cost structures.

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