Review of Test Results Conducted on Reinforcement Steel Bars

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Abstract

Where confirmatory results are required tests are conducted on specified samples by accredited material laboratories according to some accepted practices/procedures to get more information on the chemical, mechanical and technological properties of concrete reinforcement steel bars.

The mentioned properties impart a unique characteristic to each type and grade of steel. From the point of view of design and analysis the mechanical properties at yield and ultimate loads coupled with elongation at rupture are determined from tests to provide ascertained technical information to the designer as well as the analyst.

In here, a review of the accumulated steel reinforcement bar test results is undertaken to see the trend of this particular material supply from the point of view of decisive technical requirements. The review covers randomly picked test result report files of fourteen years in a row. Based on the findings there of remarks, comments and suggestions will be forwarded to create awareness regarding the short comings sneaking in the construction industry through the improper use of reinforcement bar.

Keywords: Concrete reinforcement steel; mechanical properties; elongation; true stress; true strain; ductility; toughness.

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1. Introduction

Steel as a construction material has become a fundamental component in many aspects. Its suitability for the work emanates from its:

1. Formability to any desired shape and dimension;
2. Good applicability both in the elastic, inelastic and plastic range; i.e., strength and toughness;
3. Easy recyclability, if the need arises, example, Scrapes;
4. Convenience in the creation of multi-nature connections (such as welding), etc….

One of the areas where steel is employed as a construction material is in the reinforced (cast in-situ and precast) and pre-stressed concrete. As a matter of practice and working standard guide lines a confirmatory test is conducted on specified test specimens to get a reliable data for the purpose of design and analysis concrete structures.

Since there are national, regional and international standard specifications to be adhered to; test results are referred to any of the governing ones relevant to the

obligatory agreements reached or opted for.

In this work, though ASTM A370 and ASTM A 615 are used as a basis for test result interpretation, BS 4449:97 and other relevant standard specifications, books, specialist literatures and journals were consulted for an exhaustive analysis and interpretation of the test result data of 105 (thirty five sets) reinforcement bar specimens.

2. Objective

The general objective of this assessment work is to have a bird's eye view on reinforcement bar test results from an over fourteen years accumulated data files. The specific objectives are:

1. To probe what the mechanical properties and related characteristics of re-bars look

   like in the fourteen years time span.

2. To suggest unifying methods of collecting re-bar samples to provide a reliable

   engineering data to the practicing professional in the construction industry.

3. General Theory

To interpret the data obtained from a monotonic uni-axial reinforcement bar test for the purpose of design and analysis a conventional stress vs. strain curve is plotted if sufficient points are recorded or get it directly from an autographic diagram. This graphical presentation elevates the visualization of the practicing professional to grasp under what situation structural elements are working.

Although we can get valuable design information through such a process it is not scientifically accurate, since stress as well as strain is measured throughout the test on the basis of the original dimension of the given specimen. Even though it is believed that the errors manifested in the elastic and early plastic deformation ranges are small they can be ignored. In the latter phase of the plastic deformation, however, the cross-section of the specimen reduces rapidly where by the true stress value augments till the point of breaking. Here is the paradox in the plots of stress vs. strain for practical application, the load increment goes on to maximum prior to rupture and decreases thereafter. This indicates that the material under consideration is not fully utilized to its material load carrying capacity. It is timidly utilized as shown in Figure 1(for ductile materials, steel amongst them).

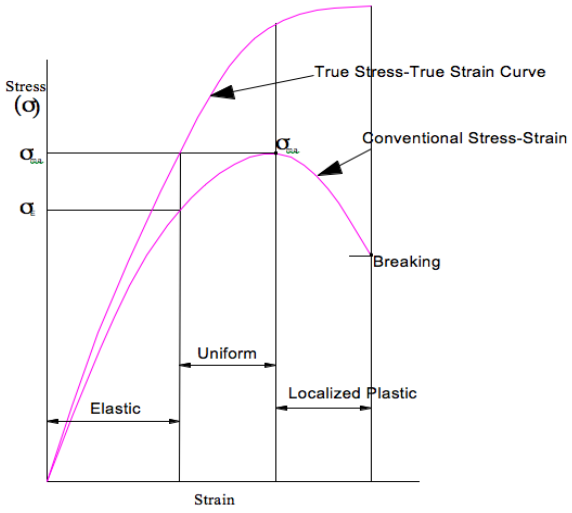


Figure 1: Conventional and True Stress-Strain Curves (Wasington.edu/.../, www/http:SRM University) [1, 2]

The inbuilt inaccuracy of the test result interpretation is an advantage to the structure to be designed; because the maximum stress to which the specimen can be subjected to is much higher than the actual rupture load considered in the design, introducing a greater margin of safety to the material design strength. That is to say, most part of the work hardening strength is lost (neglected) in the actual practice.

Moreover, Figure 1 is meant to show the differences between conventional/engineering and true stress-strain curves. The conventional is the one plotted after dividing the instant load in real time to the nominal cross-sectional area of the bar under test. If however, this same load is happened to be divided by the instantaneous real time area of the bar under tension, the stress value would be higher due to its action on

a reduced cross-sectional area of the test specimen (compare all the values in Table 1, columns 10 and13). This is more realistic than the conventional stress-strain curve. Even then, the conventional curve is accepted for a practical application; professionally.

4. Test Method

Before conducting the test, specimens were visually checked for surface defects; like, excessive corrosion. Using a prick punch mark machine the specified mid-200 mm length of each piece was marked for a latter reading of the total elongation/extension.

Then tests were conducted according to ASTM A370 procedures. A minimum of three specimens from each diameter type were brought to the laboratory by various clients. The standard length employed was 1000 mm for all diameters of bars.

The equipment used was the Universal Testing Machine (the Universal Lever-Pendulum Type) having a vertical mount for the test specimen. The operation was the combination of manual, electrical and hydraulic.

The application of the load was in a quasi-static manner. The load increment was controlled by the operating technician through a hand lever and a micro-control hand wheel. In fact, the loading process was carefully regulated by the load in the elastic range and by the strain in the plastic. The required test results were recorded tracking the anticipated manifestations of the load deformation response of each test piece.

Here it has to be noted that the load increment was not carried out in a predetermined uniform quantified value form; but gradual and smooth. Though the machine had an autographic recorder (autographic diagram plotter) it was not used at all in all the tests performed.

In the process of testing two important load readings were taken; i.e., yield point load (where, despite increasing deformation the load reading gauge remains at a standstill for the first time) and the ultimate or breaking load.

At the end of each test the two separate pieces of the broken specimen were then brought together on a level test bench (end to end) and the elongation measured within the already marked gauge length of 200 mm. This then is converted into percent elongation for the third needed technical engineering parameter. The prime mechanical properties required from such tests are:

$$\text{(i) Yield Point Stress} = \frac{\text{Yield load}}{\text{Original cross-sectional area of bar}}$$

$$\text{(ii) Ultimate Stress} = \frac{\text{Ultimate (Breaking) load}}{\text{Original cross-sectional area of bar}}$$

$$\text{(iii) Percent Elongation} = \frac{\text{Increment in length}}{\text{Original specimen length}} \times 100$$

According to EBCS 2-1995 [3], the figures obtained from the relations (i) and (ii) are characteristic and are changed to design values using the standard relation of:

$$f_{yd} = \frac{f_k}{\gamma_m} \quad \ldots\ldots (1)$$

Where,

f_{yd} = design strength
f_k = characteristic strength from test
γ_m = partial safety factor for materials

Also by taking a minimum of six diameter readings using a digital vernier caliper; three on each broken separate specimen pieces an average diameter value was determined to represent the possible bar diameter at the ultimate (rupture) load (column 3, Table 1).

5. Data Source and Methodology

In this work the primary data are collected from on hundred and two specimens of thirty-four test sets brought to the laboratory by various clients, Table 1.

The range of the nominal diameter of the bars is between 10 mm and 25 mm. Out of the hundred and two specimens twenty-four pieces i.e., eight test sets were from a then newly established local producer.

To examine the basic mechanical properties of the re-bars, some more indices were added; which are: measured diameter, calculated diameter, stress ratio, two more bar areas, two more stress values, relative area reduction (%) and relative contraction (%). All of these are calculated using the mathematical relations and expressions given in the sequel sections six and seven of this article. The mentioned results are given in Table 1; columns: 3, 4, 5, 8, 9, 12, 13, 14, and 15; respectively. These numerical values are taken as a basis for result discussion and analysis.

6. Analytical Basis

In order to fully understand the behavior of steel reinforcement bar under the conventional tension test one has to calculate two independent categories of indices. These are:

1. Strength indices (engineering), such as elastic stress, proportional limit stress and yield point stress.

2. Ductility indices, such as; relative elongation and relative reduction of area (Table 1, columns 6 and 14).

It should be remembered that the ultimate tensile strength is also important in that it sets an upper limit to the load bearing capacity of a structural member; the relative magnitudes of yield point and ultimate tensile strengths are valuable in determining safety margins also.

However, beyond the elastic limit (yield point) though there is a decrease in cross sectional area the element under investigation goes on absorbing more load. This is from the end of yield plateau (lower yield strength) where strain hardening initiates; according to Washington.edu/…/[1].The elongation continues up to the point of rupture; which is expressed as:

- Volume = $(\Pi\ D_o^2)h$, (as area decreases elongation increases; in so doing the overall volume is preserved, which implies volume constancy).
- Plastic hardening (work hardening) or cold working is taking place.

The above two points lead to the two ductility indices mentioned earlier.
Relative elongation ($\in_r$)

$$\in_e = \frac{(l_f - l_o)}{l_o} * 100 \quad \ldots\ldots (2)$$

Relative reduction of area (η_r)

$$\eta_e = \frac{(A_o - A_f)}{A_o} * 100 \quad \ldots\ldots (3)$$

Then, from the conservation of volume relationship for plastic deformation;

$$A_o l_f = A_o l_o \quad \ldots\ldots (4)$$

And the elongation based upon a very short gauge length near fracture is given by:

$$\in_o \equiv \frac{\eta_r}{(1-\eta_r)} \quad \ldots\ldots (5)$$

Where,

D_o = bar original diameter

h = bar mid-length based on the 200 mm marked gauge

A_o = bar original area

L_o = bar original length

A_f = bar area at fracture

$\hat{I}_o$ = elongation based upon a very short gauge length

h_r = relative reduction of area

Moreover, the ductility of a specified material depends upon the main values characterizing its mechanical properties.

(a) ductility index $(d_i) = \frac{\sigma_u - \sigma_y}{m} \quad \ldots\ldots (6)$

Where,
d_i = ductility index
σ_u = true failure stress (at fracture)
σ_y = Yield point stress
m = modulus of strain hardening/modulus of plastic hardening (Figure 2)

(b) toughness $(t) = \frac{\sigma^2_u - \sigma^2_y}{2m} \quad \ldots\ldots (7)$

Where

Where,

t=the amount of work to carry the material to failure

Referring to the data in Table 1, and assuming that all other conditions do remain the same, a careful synthesis of the result can lead to a fuller understanding of the intrinsic behavioral characteristics of the specified test specimens or the reinforcement steel bars.

It could be observed that there is a significant difference between the diameter values (quantity wise) those calculated based on volume constancy and the one measured at the end of each test (Table 1, columns 3 and 4).

On the account of energy dissipation the difference in diameter and there by the notion of the original bar area is taken care of by the work hardening (plastic hardening) process. This in turn is measured by the modulus of plastic hardening based upon the true stress (s_t) – true strain (e_t) curve, Figure 2.

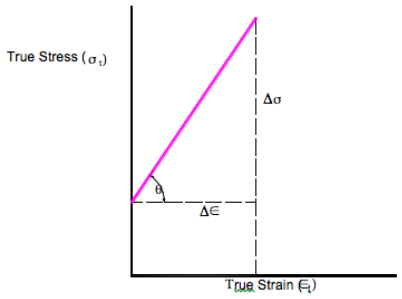


Figure 2.: Stress vs. Strain for the Modulus of Plastic Hardening(m)-(washington.edu/.../, www/bttp:SRM University [1, 2])

$$\sigma_t = \frac{P_{max\,(t)}}{A_f} \quad \text{.....(8)}$$

and

$$m = \tan\theta = \frac{\Delta\sigma}{\Delta\in} \quad \text{.....(9)}$$

Where,

Pmax(t)=maximum load from the true stress-true strain curve

Af = cross-sectional area at fracture

Ds = change in stress

DÎ = change in length corresponding to the change in stress

q = an angle formed between the straight line and the x-axis in the plastic

range of the true stress-true strain curve

Again, the toughness (t) is also the same as the energy required to rupture the specimen at failure, expressed in Newton-m/m2. For which the work hardening process is the one which contributes to structural elements to withstand severe overload or time dependent repeated occasional loads (hysteresis).

7. Result Discussion and Analysis

According to relevant literatures, the minimum ultimate stress to be attained by any reinforcement bar is at least higher than by 10% of the yield stress for that same material. Regarding this issue, the Ethiopian Standard (ES ISO 6935-2: 2012) [4] and Construction Standard : 2012 [5] do suggest ranges of 2%-25% and 13%-38% based on the specified characteristic value of tensile strength to upper yield strength ratio of the specimens; respectively.

Referring to Concrete Reinforcement Steel Institute (CRSI) [6], the ultimate to yield stress ratio is given as: for structural steel 1.66 to 2.12, for intermediate grade steel 1.75 to 2.12 and for hard grade steel 1.10 min. In light of this, the values of Table 1, column 5 of these ratios are 1.16 to 1.82 and for more than 94% of the specimens is less than 1.66. The indication is that the re-bar grades in the market then ebbed on the hard steel regime of the spectrum.

In addition, the second ductility property (specified characteristic value of elongation) is noted as to be in the range of 13-17% within a specified gauge length of 200mm (8”), as stated in ES ISO 69352-2:2012 [4]. From Table 1, column 6 it can be easily observed that,

the elongation results are in the range of 12 to 30%. In comparison, the results are in a better match at the lower end and very much exceed the upper limit.

Duggal, S.K. mentions, “At yield stress or 0.2% proof stress, mild steels of grades I and II have a minimum elongation of 23% for all diameters up to 50mm. Even nowadays, it is as engineers friendly as before in the under developed and developing countries.” [7].This again shows that, the results attained are not very far from proven realities.

Regarding this same issue the work of Gupta S. (2012) states that, “if bars do not crack during fabrication, any excess elongation is irrelevant” [8]. Hence, it needn’t be a matter of much concern in here.

On the other hand, due to the following possible errors the results are liable to any technical challenge.

- No information was available on how the sampling was done. For example, if all the three test pieces were taken from the same bar of 12 meter length; the recorded results do not represent the reality. Regarding this, so many anomalies could be cited which require due attention.
- The manual control of loading casts doubt on the observed discrepancies in test results. However, such un-certainty is justified where high yield and low yield bumps/kinks are difficult to observe during the test. But, this was thoroughly followed and noted all along the test by the supervising expert (jotting down the loads around these points). According to Rebar Tensile Testing Guide regarding testing speeds and control, it states that: “One of the most challenging aspects of complying with test standards is determining how to properly and efficiently execute the tensile test. Despite standards providing specific details for allowable test speeds and control modes for the different stages of the test, it can still be difficult to perform the test properly. This may relate to standard interpretation challenges and the limitations of the test equipment. This can make it very difficult to fully understand all aspects of the test process and how to make it work on a given testing system” [9].
- Since the local market looked haphazard then, even if it was tried out to find as what went wrong; there is no a traceability mechanism to earnestly understand the transaction that took place in the lengthy process of re-bar manufacturing and merchandizing. The work of Balogun, S., et al. discusses that, “most steel plants in Nigeria have high scrap input compared with the use of virgin charges. Innovative processing methods that integrate chemically sound rolling stock, controlled thermal variation and controlled cooling are imperative” [10]. In which case, the anomalies in the results in here can be due to the breach in the quality of the parent material and/or somewhere in the whole process all along.

Keeping all the above intricate situations in mind, it can be stated that, if the samples brought to the lab were selected for testing according to the directives stated in any of the nationally or internationally accepted standard specifications all those tested materials looked sound enough; though they require the professional’s (end user’s) careful judgment and proper referencing of standard codes of practices for the intended use as far as the mechanical properties are concerned.

This statement applies to the level of design based on Hookean material; which is more often practical in the working stress design (WSD) method. If, however, we cross the threshold value of yield the design problem would be quite different. This is where the theory of plasticity applies (i.e., plastic design).

As can be clearly observed, there is a big range of material load carrying capacity in terms of strength and ductility. That means then, if one tries to use this building material economically and effectively opting for the plastic design philosophy is more realistic.

Moreover, the conventional stress-strain curve (engineering) is by far less than the true stress-true strain curve. This can be verified through a uni-axial tensile test on cylindrical test specimen; which enables to see:

1. The true fracture stress, the load at fracture divided by the cross-sectional area after fracture (Equation 8 and column 13 of Table 1).

2. The true fracture strain, the true strain based on the natural logarithmic ratio between the original area and the area after fracture, (Equation 10 and

$$\epsilon_t = 1_n \left[\frac{A_0}{A_f} \right] \quad \text{.....} \quad (10)$$

This parameter represents the maximum true strain that the material can withstand just before fracture and is analogous to the total strain to fracture of the conventional and true stress-strain curve of Figure 1.

Beyond the onset of necking, it is not possible to calculate the true fracture strain from measured values of strain. But can be derived from a relation which is based on the reduction in area as;

$$\epsilon_t \left[\frac{}{1-\eta_r} \right] = 1_n \quad \text{.....} \quad (11)$$

Where, h_r is as in equation 3 and the results are in column 14 of Table1.

Moreover, in Table 1, four diameters are indicated for each and every single specimen. These diameters are those:

1. Prescribed by the client in the work order (nominal)-col.1,

2. Measured prior to conducting the test (virgin material)-col.2,

3. Measured immediately after the test, (broken pieces)-col.3, and

4. Calculated using the following relation-col.4.

5. $D_c = Do^2 x 200$ ½ (from constancy of volume)……..(12)

l_f

Where,

D_c = final diameter at fracture (calculated)

D_o = original diameter

l_f = final length of specimen after fracture

The comparison between the bar diameters after fracture and the one calculated using the given expression has a significant difference. This difference is the invisible dimension where the secret of reduction in cross-sectional area and the absorption of more load is enshrined.

One can simply observe that if the given specimen was to fail at the indicated load it would had had the diameter designated by D_c (calculated) as in column 4, Table 1. But on the contrary the actual is the one shown as measured diameter after test (final) column 3, Table 1.

All the above are from a uni-axial and unidirectional tensile test. In real situation loads on structural elements can be (and are) of pulsating and/or hysteretic in nature. To this, the response of individual element is quite varied. Under such circumstances load reversals (stress reversals) are possible. If this continues with time the element under consideration will search a point where its capacity both in tension and compression will be limited till the point of failure. This then leads to the concept of number of cycles required for a given element or a structure to fail. This phenomenon is partially made possible by the unaccounted for energy absorbing capacity of structures and their components.

8. Conclusion and Suggestions

8.1. Conclusion

As the calculated values in Table 1 show, the differences in: percentage elongation, all the calculated stresses, percentage area reduction and relative contraction of the cross-sections within a given set of test specimens after rupture are in close agreement with each other; even under such challenging circumstances of materials handling. This indicates that, if better industrial and market mechanisms were in place, the means of getting highly reliable engineering data would have been availed for the practicing professional. Hence, the randomly selected but few re-bar specimen test results over a time span of fourteen years are not in big disparities in numerical value terms.

It can then be concluded that the analyzed test results have revealed that the concrete reinforcement bars supplied to the market be it imported or produced locally fulfilled the requirements set for the purpose of control in one way or another. However, the overall situation relegates the full responsibility to the professional who is supposed to be ethically equipped to use the data very cautiously. As a deterrent, since this assessment is very modest large scale scheduled market and industrial re-bar supply trends must be kept under surveillance to ensure the costly infrastructure well being and the value for money of our overall development.

8.2. Suggestions

To create a better level of confidence among the design and analysis professional

community technical awareness and dissemination of basic information with

obligatory delineating products with well defined markings at every sales point

must be sanctioned. This will as well protect the market from sub-standard

re-bar supplies.

Those laboratories giving re-bar test services must enforce such important

sales point markings as part of any lab test procedure or be involved in the

sampling process of specimens them-selves.

Guide lines must be in place to assist consumers/ buyers on how test samples

should be collected/obtained from a certain consignment/batch.

iv. It is high time that the ES ISO 6935-2: (2012) [4] incorporate in its mandatory

volume a section as in Construction Standard (2012) [5] : PURCHASER'S

TESTS OF STEEL REINFORCING BARS; which states: "Steel reinforcement

bars arriving on site shall be tested by the purchaser. All tests shall be performed

by an accredited laboratory. For each batch of steel reinforcing bars delivered

to site, test specimens shall be taken from different bars in the batch to undergo

the purchaser's testing for which the rate of testing shall be in accordance with an

already provided reference table in the cited standard."

v. There has to be a market surveillance from time to time to track the technical

consistency and conformity of reinforcement bars to applicable standards.

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Table 1: Cross Section Property, Stress and Strain

Nominal	Various Diametres (mm) measured Initial	Various Diametres (mm) measured Final	Various Diametres (mm) calculated	Stress Ratio (Бu/Бy)	Elongation (%)	Bar Area(mm2) Initial	Bar Area(mm2) Final	Bar Area(mm2) Calc.	Stresses(kg/mm2) Yield	Stresses(kg/mm2) Max.load	Stresses(kg/mm2) Calc.	Stresses(kg/mm2) Final	Area Reduction (%)	Relative Contraction (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
14	13.47	10.37	12.56	1.32	15.0	142.50	84.46	123.90	63.16	83.11	95.59	140.22	40.73	23.01
	13.29	10.99	12.39	1.33	15.0	138.72	94.86	120.57	62.00	82.90	95.38	121.23	31.62	17.31
	13.23	10.58	12.39	1.28	14.0	137.47	87.91	120.57	65.83	84.39	96.21	131.95	36.05	20.00
25	24.21	20.09	21.79	1.64	23.5	460.34	316.99	372.91	38.45	63.00	77.77	91.49	39.94	17.02
	24.19	20.20	21.95	1.64	21.5	459.58	320.47	378.41	38.59	63.65	77.30	91.27	30.27	16.49
	24.31	20.43	21.96	1.67	22.5	464.15	327.81	378.75	38.13	63.34	77.62	89.69	29.37	15.96
12	11.28	9.67	10.56	1.35	14.0	99.93	73.44	87.58	63.04	85.06	97.05	115.70	26.51	14.27
	11.42	9.72	10.74	1.28	13.0	102.43	74.20	90.59	64.43	82.50	93.27	113.88	27.56	14.89
	11.35	9.76	10.65	1.25	13.5	101.18	74.82	89.08	61.77	77.09	87.56	104.25	26.05	14.01
14	13.33	11.58	12.51	1.33	13.5	139.56	105.32	122.91	63.41	85.06	97.22	113.46	24.53	13.13
	13.42	11.15	12.33	1.35	14.5	135.19	97.64	119.40	65.46	88.02	99.66	121.88	27.78	15.02
	13.20	11.41	12.34	1.35	14.5	136.85	102.25	119.60	64.67	87.69	100.34	117.36	33.84	13.56
16	14.72	11.58	13.81	1.33	17.0	170.18	105.32	149.79	62.29	83.44	94.80	134.83	38.11	21.33
	14.57	10.71	13.65	1.27	14.0	166.73	90.09	146.34	68.37	85.17	97.04	157.62	45.97	26.49
	15.67	9.93	14.64	1.18	14.5	192.85	78.38	168.33	64.30	75.71	86.73	186.27	59.36	36.25
24	23.20	17.16	21.13	1.79	20.5	422.73	231.27	350.60	34.54	61.98	71.86	113.29	45.29	26.03
	23.26	17.67	20.95	1.79	23.0	424.92	245.22	344.79	33.89	60.72	74.84	105.21	42.29	24.03
	23.14	17.54	20.74	1.72	24.5	420.55	241.63	337.84	34.24	59.21	73.70	103.05	42.54	24.20

Nominal	Various Diametres (mm) measured Initial	Various Diametres (mm) measured Final	Various Diametres (mm) calculated	Stress Ratio (Бu/Бy)	Elongation (%)	Bar Area(mm2) Initial	Bar Area(mm2) Final	Bar Area(mm2) Calc.	Stresses(kg/mm2) Yield	Stresses(kg/mm2) Max.load	Stresses(kg/mm2) Calc.	Stresses(kg/mm2) Final	Area Reduction (%)	Relative Contraction (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
16	15.41	11.58	14.31	1.16	16.0	186.51	105.32	160.83	70.45	82.03	95.13	145.27	45.53	24.85
	15.37	11.11	14.24	1.49	16.5	185.54	96.94	159.26	53.90	80.85	94.18	154.73	47.73	27.72
	15.44	11.65	14.34	1.54	16.0	187.23	106.60	161.51	51.27	78.51	91.02	137.90	43.06	24.55
20	19.52	14.41	18.01	1.54	17.5	299.26	163.09	254.75	48.12	73.85	86.75	135.51	45.50	26.18
	19.54	14.65	18.10	1.54	16.5	299.87	168.56	257.30	48.02	73.37	85.50	130.52	43.79	25.03
	19.40	14.56	17.90	1.54	17.0	295.59	166.50	251.65	48.38	74.43	87.42	132.13	43.67	24.95
12	11.51	7.85	10.42	1.52	22.0	104.05	48.40	85.28	45.17	69.20	84.43	148.76	53.48	12.74
	11.89	9.87	10.79	1.49	21.5	111.03	76.51	91.44	41.88	62.60	76.01	90.37	31.09	16.99
	11.90	8.42	10.82	1.52	21.0	111.22	55.68	91.95	41.81	63.84	77.22	127.51	49.98	29.24
16	15.71	11.83	14.19	1.56	22.5	193.84	109.92	158.14	39.98	62.94	77.14	110.59	43.29	24.70
	15.69	11.77	14.03	1.56	25.0	193.35	108.80	154.60	40.34	63.36	79.24	112.59	43.73	24.98
	15.54	11.69	14.04	1.56	22.5	189.67	107.33	154.82	40.86	64.32	78.80	113.67	43.71	24.77
20	19.71	13.83	17.59	1.56	25.5	305.11	150.22	243.01	39.99	62.93	79.01	127.81	50.77	29.53
	19.72	13.84	17.64	1.56	25.0	305.42	150.44	244.39	40.27	62.86	78.56	127.63	50.74	29.82
	19.66	13.66	17.59	1.56	25.5	303.57	146.35	243.01	40.52	63.25	79.01	131.01	51.72	30.52
25	24.86	18.76	21.89	1.61	29.0	485.39	276.41	376.34	39.56	63.87	82.37	112.15	43.05	24.54
	24.77	18.97	22.29	1.59	23.5	481.88	282.63	390.22	37.77	60.18	74.32	102.61	41.35	23.42
	24.70	18.40	22.14	1.61	24.5	479.16	265.90	384.99	37.56	60.52	75.33	109.06	44.31	25.51

Nominal	Various Diametres (mm) measured Initial	Various Diametres (mm) measured Final	Various Diametres (mm) calculated	Stress Ratio (Бu/Бy)	Elongation (%)	Bar Area(mm2) Initial	Bar Area(mm2) Final	Bar Area(mm2) Calc.	Stresses(kg/mm2) Yield	Stresses(kg/mm2) Max.load	Stresses(kg/mm2) Calc.	Stresses(kg/mm2) Final	Area Reduction (%)	Relative Contraction (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
16	15.30	10.99	13.68	1.32	25.0	183.85	97.86	146.98	60.38	79.96	100.01	150.21	46.77	28.17
	15.40	11.03	13.83	1.33	24.0	186.26	95.55	150.22	58.52	78.39	97.19	152.80	48.70	28.38
	15.60	10.65	14.09	1.35	22.5	191.13	89.08	155.92	56.51	76.39	93.64	163.89	53.39	31.73
24	23.70	18.79	20.99	1.49	27.5	441.15	277.30	346.03	54.40	81.60	104.04	129.82	37.94	22.91
	23.70	17.91	21.20	1.39	25.0	441.15	251.93	352.99	53.27	73.67	92.07	129.00	42.89	24.43
	23.80	18.07	21.08	1.43	27.5	444.80	256.45	349.00	49.46	70.26	89.54	121.86	42.34	24.08
10	9.69	6.80	8.79	1.41	21.5	73.75	36.32	60.68	50.85	71.19	86.52	144.55	50.75	29.83
	9.66	6.95	8.73	1.47	22.5	73.29	37.94	59.86	50.48	74.36	91.05	143.65	48.23	28.05
	9.79	7.25	8.88	1.43	21.5	75.28	41.28	61.93	50.48	72.40	88.00	132.03	45.17	25.95
10	9.76	5.77	8.63	1.33	28.0	74.82	26.15	58.49	40.76	54.13	69.24	154.88	65.05	40.88
	9.68	6.08	8.57	1.32	27.5	73.59	29.03	57.68	42.13	55.71	71.08	107.75	48.30	28.10
	9.79	6.35	9.13	1.35	29.0	31.67	35.14	65.47	37.86	51.14	58.81	121.57	57.93	39.14
12	11.89	9.08	10.43	1.52	30.0	111.03	64.75	85.44	46.83	70.70	91.88	124.24	41.68	23.63
	11.78	8.95	10.33	1.49	30.0	108.99	62.91	83.81	48.17	71.57	93.07	125.18	42.28	24.02
	11.91	8.56	10.55	1.52	27.5	111.41	57.55	87.42	46.67	70.46	89.80	136.40	48.34	28.13
25	24.13	15.26	21.58	1.59	25.0	457.30	182.89	365.76	37.83	60.35	75.46	150.91	60.01	36.76
	24.51	17.98	21.50	1.64	30.0	471.82	253.90	363.05	37.51	61.25	79.60	113.82	46.19	26.64
	24.31	16.05	21.65	1.61	26.0	464.15	202.32	368.13	38.35	62.48	78.78	143.34	56.41	33.98

Table 1: Continued.....

Nominal	Various Diametres (mm) measured Initial	Final	calculated	Stress Ratio (Бu/Бy)	Elongation (%)	Bar Area(mm2) Initial	Final	Calc.	Stresses(kg/mm2) Yield	Max.load	Calc.	Final	Area Reduction (%)	Relative Contraction (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
12	11.64	9.49	10.56	1.59	21.5	106.41	70.73	87.58	43.23	69.07	83.92	103.91	33.53	18.47
	11.72	9.72	10.61	1.49	22.0	107.88	74.20	88.49	45.42	67.67	82.57	98.38	31.22	17.06
	11.87	10.17	10.72	1.49	22.5	110.66	81.23	90.26	44.28	66.42	81.43	81.23	26.59	14.32
16	15.79	11.98	14.12	1.59	25.0	195.82	112.72	156.59	39.58	62.56	78.23	108.68	50.76	29.83
	15.79	11.50	14.07	1.59	26.0	195.82	103.87	155.48	39.32	62.05	78.14	116.97	46.96	27.17
	15.80	11.88	14.28	1.56	22.5	196.07	110.85	160.16	39.27	61.71	75.55	109.16	43.46	24.81
10	9.51	6.17	8.95	1.20	13.0	71.03	29.90	62.91	68.98	83.06	93.78	197.32	57.91	35.12
	9.59	5.68	9.02	1.25	13.0	72.23	25.34	63.90	66.45	83.07	93.90	236.78	64.92	40.77
	9.48	6.23	8.92	1.23	13.0	70.58	30.48	62.49	69.42	85.72	96.81	198.49	56.89	34.29
12	10.96	7.40	10.36	1.30	12.0	94.34	43.01	84.30	68.89	89.04	99.65	195.30	54.41	32.48
	11.02	8.58	10.41	1.27	12.0	95.38	57.82	85.11	67.62	85.97	96.34	141.82	39.39	22.14
	11.32	7.73	10.67	1.27	12.5	100.64	46.93	89.42	65.08	82.47	92.82	176.86	53.37	31.71
16	14.85	11.91	14.01	1.40	13.0	173.20	111.41	154.96	58.86	80.40	90.82	125.66	36.02	19.80
	15.01	10.41	14.00	1.40	13.5	176.95	85.11	155.92	57.93	79.12	89.79	164.49	51.90	30.65
	15.05	11.21	14.16	1.40	13.0	177.89	98.70	157.48	57.34	78.42	88.58	141.34	44.52	25.51
20	18.89	14.15	17.85	1.35	12.0	280.26	157.25	250.25	56.38	76.36	85.51	136.09	43.89	25.09
	18.74	14.46	17.59	1.35	13.5	275.82	164.22	243.01	56.56	76.86	87.24	129.10	40.46	24.49
	18.63	14.33	17.53	1.32	13.0	272.59	161.28	241.35	54.29	71.90	81.21	121.53	40.83	23.08
25	23.64	19.96	22.29	1.45	12.5	438.92	312.90	390.22	47.62	68.81	77.39	96.52	28.71	15.52
	23.53	19.23	22.18	1.47	12.5	434.84	290.43	386.38	47.37	69.68	78.42	104.33	33.21	18.27
	23.67	18.73	22.27	1.49	13.0	440.03	275.53	389.52	50.45	74.99	84.72	119.77	37.38	20.87

Nominal	Various Diametres (mm) measured Initial	Final	calculated	Stress Ratio (Бu/Бy)	Elongation (%)	Bar Area(mm2) Initial	Final	Calc.	Stresses(kg/mm2) Yield	Max.load	Calc.	Final	Area Reduction (%)	Relative Contraction (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
10	9.90	7.28	9.13	1.54	17.5	76.97	41.62	65.47	54.47	83.80	98.52	154.97	45.93	26.46
	9.85	7.02	9.15	1.49	16.0	76.20	38.70	65.76	56.43	84.65	98.09	166.67	49.21	28.73
	9.88	7.18	9.17	1.54	16.0	76.67	40.49	66.04	54.78	83.80	97.28	158.68	47.19	27.33
12	11.43	7.85	10.57	1.49	17.0	102.61	48.40	87.75	53.60	79.91	93.45	169.42	52.83	31.32
	11.50	7.62	10.63	1.52	17.0	103.87	45.60	88.75	52.95	79.91	93.52	182.02	56.10	33.74
	11.55	7.81	10.66	1.47	17.5	104.77	47.91	89.25	53.45	79.22	93.00	173.24	54.27	32.38
14	13.58	9.45	12.55	1.54	17.0	144.84	70.14	123.70	56.61	86.99	101.86	173.64	51.57	30.41
	13.55	9.41	12.53	1.49	17.0	144.20	69.55	123.31	56.87	84.95	99.34	176.13	51.77	30.55
	13.84	9.56	12.77	1.54	17.5	150.44	71.78	128.08	54.51	83.75	98.38	175.94	52.29	30.93
16	15.55	10.49	14.35	1.52	17.5	189.91	86.43	161.73	51.60	77.93	91.51	171.24	54.49	32.54
	15.36	10.81	14.32	1.49	15.0	185.30	91.78	161.06	52.89	79.33	91.27	160.12	50.47	29.62
	15.32	11.75	14.04	1.49	19.0	184.33	108.43	154.82	53.17	79.75	94.95	135.58	41.18	23.30
20	20.10	13.79	18.31	1.52	20.5	317.31	149.35	263.31	44.12	67.44	81.27	143.29	52.93	31.39
	20.31	14.40	18.30	1.52	20.5	323.97	162.86	268.80	42.60	66.06	79.61	131.40	49.73	29.10
	20.10	14.06	18.31	1.54	20.5	317.31	155.26	263.31	43.81	67.76	81.65	138.48	51.07	30.05

Nominal	Various Diametres (mm) measured Initial	Final	calculated	Stress Ratio (Бu/Бy)	Elongation (%)	Bar Area(mm2) Initial	Final	Calc.	Stresses(kg/mm2) Yield	Max.load	Calc.	Final	Area Reduction (%)	Relative Contraction (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
24	25.16	17.83	22.97	1.64	20.0	497.18	251.09	414.39	46.26	75.43	90.49	149.35	49.50	29.13
	25.29	17.66	23.13	1.61	19.5	502.33	244.95	420.19	45.79	74.45	89.00	152.68	51.24	30.17
	25.25	17.90	23.05	1.61	20.0	500.74	251.65	417.28	45.93	74.29	89.15	147.82	49.74	29.11
20	19.60	14.03	17.53	1.61	25.0	301.72	154.60	241.35	39.44	63.97	79.79	124.84	48.76	28.42
	19.72	15.29	17.74	1.59	23.5	305.42	183.61	247.17	39.78	62.86	77.68	104.57	39.88	24.47
	19.50	15.46	17.10	1.56	30.0	298.65	187.72	229.66	40.85	64.29	83.60	102.28	37.14	20.72
14	14.31	8.16	13.34	0.59	15.0	160.83	52.30	139.77	24.87	43.28	48.65	130.02	67.48	42.98
	14.21	8.26	13.35	1.64	13.5	158.59	53.59	139.77	25.22	41.62	47.15	123.16	66.21	41.87
	14.07	7.84	13.21	1.82	13.5	155.48	48.27	137.06	23.15	41.81	47.43	134.66	68.95	44.28
16	15.5	11.95	13.34	1.52	35.0	112.16	189.00	139.77	51.00	77.00	103.74	129.28	40.66	22.90
	15.5	11.73	13.34	1.52	35.0	108.07	189.00	139.77	48.00	73.00	98.73	127.70	42.82	24.32
	15.4	11.67	13.77	1.52	25.0	106.90	186.00	148.92	49.00	74.00	92.67	129.09	42.53	24.22