Characteristics of Grade 60 and Grade 72.5 Re-bars in Pakistan

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Abstract: *In Pakistan, quality assurance of re-bars is practically non-existent and there is no generally accepted testing method for testing of re-bars. Steel re-bars of Grade 60 are exclusively used in Pakistan; however production of high strength re-bars has recently started. In this study, thirty samples of steel re-bars of Grade 60 and thirty samples of Grade 72.5 were tested using ASTM standard testing protocol to obtain the stress-strain curves and comparisons were made between the experimental results of Grade 60 and Grade 72.5 re-bars. It can be concluded that Grade 72.5 steel shows less deformation capacity as compared to Grade 60 steel. For Grade 60 re-bars, the yield strengths of all individual re-bars were much higher than the prescribed minimum yield strength, i.e. 60 ksi. For the Grade 72.5 re- bars, about 50 % of the re-bars did not reach the prescribed minimum yield strength of 72.5 ksi.*

The experimental curves were then compared with an idealized stress-strain curve developed by using a fractional equation. It is recommended that instead of producing Grade 72.5 ksi reinforcing bars, the traditional ASTM Grade 75 reinforcing bars be produced.

Keywords: *idealized curve, standardize, stress strain curve, Tension tests*

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I. INTRODUCTION

There are number of standards which cover the testing of re-bars in Pakistan. These include; ASTM Standards [1], BS Standards [2], ISO Standards [3] and PS Standard [4]. Pakistan Standards and Quality Control Authority (PSQCA) has adopted a slightly revised/modified version of BS 4449-2005 [2] standard and this standard is PS-1612-2007 [4]. The contents of PS-1612-2007 [4] are essentially the same as BS 4449-2005 [2]. For quality assurance, some agencies prefer to use portions of ASTM A615 [1] test standards and portions of BS 4449-1997 or BS 4449-2005 test standards. The use of portions of one standard and portions of the other standards is not technically correct and should not be permitted. A summary of the review of the standards [1-4] is presented in Table 1.

In Pakistan, steel bars are manufactured using variety of sources. Steel re-bars manufactured from ship scrap materials are likely not to exhibit adequate deformation capacity or ductility. This study was initiated to develop a standard testing protocol to be adopted in Pakistan for standardized testing of re-bars in Pakistan. Evaluation of testing protocol at facility of one re-bar manufacturer and one academic institution was conducted. With slight modification, the testing protocol at NED University of Engineering and technology (NEDUET) Materials Testing Laboratory was made in conformance with ASTM A615 Standard [1]. It is recommended that one internationally recognized test standard should be adopted and used in Pakistan for the testing and quality assurance of re-bars.

Using ASTM A615 [1] testing protocol, thirty samples of #5 bars, (16 mm) of Grade 60 re-bars and thirty samples of #5 bars, (16 mm) Grade 72.5 re-bars were tested and stress-strain curves were obtained. Grade 72.5 re-bars shows less deformation capacity as compared to Grade 60 re-bar steel. The experimental results were compared with idealized analytical stress-strain curve of Grade 60 (420 MPa) and Grade 72.5 (500 MPa) reinforcing bars developed by Ahmad [6, 10]. It is recommended that instead of producing Grade 72.5 ksi reinforcing bars, the traditional ASTM Grade 75 reinforcing bars be produced.

II. EXPERIMENTAL PROGRAM

In the preliminary study, an evaluation of testing protocol at facility of one manufacturer and one academic institution was conducted. For conformance with ASTM A615 Standard [1], a slight modification (adjustment in the rate of loading), was made in the testing protocol at NEDUET Materials Testing Laboratory.

Using the ASTM A615 Standard [1] and ASTM A370 [5] testing procedure, tension tests were performed for 60 samples of deformed steel re-bars. The size of bars was taken as #5 (16 mm). Thirty samples were of Grade 60 (420 MPa) rebars and thirty samples were of high strength, Grade 72.5 (500 MPa) re-bars. These tests were performed in the Material testing laboratory of NEDUET. A Universal Testing Machine of 50 tons capacity and an Extensometer were used for the tests. All the samples were cut for the required length of about 24 in (600 mm).

The tests were performed at two rates of loading, 10 mm/min (0.4 in/min) up to one half of the yield point and then rate of loading was reduced to 1.5 mm/min. (1/16 in/min) up to or near yielding. This rate of loading was maintained until the yield point, after which the rate of loading was increased to 10 mm/min (0.4 in/min) until rupture of the specimen (ASTM testing method A 370 [5]).

2.1 Results

Test results of tension tests on Grade 60 #5 (16 mm) re-bars are shown in **Table 2** and it can be observed that all of the bars show yield strength much higher than the prescribed minimum yield strength, i.e. 60 ksi. The average yield value of 30 samples is 77.2 ksi which is substantially higher than specified yield strength of 60 ksi. Stress-strain curves for 30 samples of Grade 60 #5 (16 mm) re-bars are shown in **Figure 1.**

Test results of tension tests on Grade 72.5 deformed bars #5 (16 mm) are shown in **Table 3** and it can be observed that about 50 % of the bars do not reach the prescribed minimum yield strength of 72.5 ksi. The average yield value of 30 samples is 72.7 ksi which is just above the specified yield strength of 72.5 ksi. Stress-strain curves for 30 samples of Grade 72.5 re-bars are shown in **Figure 2.**

2.1.1 Control points of stress-strain curve and Idealized stress-strain Curves

For the development of idealized analytical stress-strain curve of steel re-bars, five (5) control points are used. **Figure 3** shows the control points for an experimental stress strain curve. Using the coordinates of the control points, calibrated by Ahmad [6, 10] for about 2000 samples and the fractional equation developed by Ahmad [6, 10], idealized stress-strain curves for Grade 60 re-bars and Grade 72.5 re-bars are developed. These idealized analytical stress-strain curves are compared with the experimental stress-strain curves.

2.1.2 Average Experimental stress strain curve

The control points from test results of thirty samples of Grade 60 and thirty samples of Grade 72.5 re-bar (High strength) were averaged and the average values of the control points were obtained. **Table 4** shows the average values of the experimental control points for Grade 60 re-bars of #5(16 mm) and **Table 5** shows the average values of the experimental control points for Grade 72.5 re-bars of #5(16 mm).

Figure 4 shows the average stress-strain curve of Grade 60 #5 bars using control points of **Table 4** and **Figure 5** shows the average stress-strain curve of Grade 72.5 #5 bars using control points of **Table 5**.

2.1.3 Comparison of Average Experimental and Idealized stress strain curves

The comparison of experimental average and idealized analytical stress strain curve of Grade 60 re-bars (**Figure 6)** shows that ultimate tensile stress in the idealized stress strain curve is higher than that obtained experimentally. The deformation capacity of the re-bars tested is adequate with a strain of 0.218 %. The strain capacity in the idealized curve is 0.15 %.

The comparison of experimental average and idealized analytical stress strain curve of Grade 72.5 re-bars **(Figure7)** shows that ultimate tensile stress in the idealized stress strain curve is higher than that obtained experimentally. The deformation capacity of the re-bars tested is adequate with a strain of 0.133 %. The strain capacity in the idealized curve is 0.125 %.

III. Conclusions and Recomendations

On the basis of the results, the following conclusions can be drawn:

1. The deformation capacity of Grade 72.5 re-bars is less as compared to that of Grade 60 re-bars.
2. For Grade 60 re-bars, the yield strengths of all individual re-bars were much higher than the prescribed minimum yield strength of 60 ksi and the average yield value of 30 samples is 77.2 ksi which is substantially higher than specified yield strength of 60 ksi.
3. For the Grade 72.5 re- bars, about 50 % of the re-bars did not reach the prescribed minimum yield strength of 72.5 ksi and the average yield value of 30 samples is 72.7 ksi which is just above the specified yield strength of 72.5 ksi.

The following recommendations are made:

1. One internationally recognized standard, preferably ASTM A615 should be adopted and used in Pakistan for the testing and quality assurance of re-bars
2. Instead of Grade 72.5 re bars, Grade 75 re-bars as per ASTM A615 should be manufactured in Pakistan.

Table 1: Comparison of Existing Standards

No.	Item	ASTM A615 [1]	BS 4449-2005[2]	ISO 6935-2:2007(E)[3]
1	**Scope**	Covers both deformed and plain carbon steel bars. Standard is for grade 40 (280 MPa), grade 60 (420 MPa) and grade 75 (520 MPa)	Covers only deformed bars of grade 72.5 (500 MPa)	This Standard contains technical requirements for ten grades of ribbed (deformed) steel bars from grade 43(300 MPa) to grade 72 (500 MPa) strengths and different ductility levels.
2	**Manufacture**	Standard specifically requires the use of electric furnace, basic oxygen or open hearth process	The manufacturing process is at the discretion of the manufacturer, but it should be reported to the purchaser.	The manufacturing process is at the discretion of the manufacturer.
3	**Chemical composition**	Phosphorous content should not exceed 0.06%.	It states that values of individual elements, namely Carbon, Sulphur, Phosphorous, Nitrogen and Copper should not exceed certain limits. A value of Carbon equivalent content should also be calculated and checked against values given in Table 2 (BS 4449-2005 **[2])**	It is same as BS 4449-2005 [2].
4	**Tensile Requirement**	Elongation of 8 in (200mm) gauge length is tested and checked in percentage of original length and compared with the elongations given in Table 2 (ASTM A615 [1]. For grade 40(280 MPa) and 60(420 MPa), yield point is taken at a strain of 0.5 % and for grade 75(520 MPa) steel, yield point is taken at a strain of 0.35%.	It states that ratio of tensile /yield strength and total elongations must be in accordance with Table 4 BS 4449-2005 [2]). Determine yield strength from 0.2% proof strength if a yield phenomenon is not present.	It is similar to BS 4449-2005[2] except that it includes more grades for bars.
5	**Bending requirement**	The angle of bend should be 180° unless otherwise specified. Test is performed at room temperature. Rate of bending is not specified.	It is bent up to 90°, aged and then bent back to 20°. Test temperature is 10°-35° and rate of bending is 60 °/s.	The test piece is tested for bending over a mandrel to an angle 160° to 180°. Test temperature and rate of bending are same as BS 4449 [2]
6	**permissible variation in weight(mass)**	Only 6% variation is allowed.	±4.5% on nominal diameter greater than 0.32 inch(8mm) and ±6% on nominal diameter of bar less than 0.32in(8mm).	Permissible deviation is ±4% to ±8%, depending upon the diameter of the bar.
7	**Gauge Length of specimen**	8 inch (200mm).	5 x diameter of bar	5 x diameter of bar

Table 2: Test results of tension tests on Grade 60 deformed bars #5 (16 mm) re-bars

Tests	f_y	ε_y	f_{sh}	ε_{sh}	f_u	ε_u	f_f	ε_f
1	74.10	0.0025	77.25	0.0189	92.23	0.101	60.77	0.160
2	75.50	0.0031	76.64	0.0197	91.28	0.106	60.95	0.207
3	79.93	0.0025	82.20	0.0246	98.81	0.116	75.71	0.235
4	85.24	0.0028	87.60	0.0237	105.62	0.134	78.03	0.270
5	80.90	0.0030	81.70	0.0155	97.79	0.120	67.20	0.230
6	74.50	0.0024	78.20	0.0600	93.90	0.148	59.90	0.503
7	77.92	0.0026	77.75	0.0217	93.51	0.118	61.90	0.225
8	77.88	0.0030	77.00	0.0180	92.90	0.151	63.94	0.277
9	74.82	0.0027	79.14	0.0420	96.33	0.150	69.65	0.230
10	79.26	0.0030	80.37	0.0260	92.68	0.132	66.84	0.219
11	70.76	0.0027	70.92	0.0147	86.33	0.139	54.20	0.254
12	74.50	0.0025	76.80	0.0167	91.29	0.122	54.30	0.216
13	76.47	0.0027	77.17	0.0250	93.59	0.170	69.40	0.317
14	77.42	0.0023	78.86	0.0660	95.46	0.144	71.64	0.453
15	79.44	0.0029	79.82	0.0147	95.71	0.133	66.22	0.246
16	71.98	0.0023	81.04	0.0170	95.27	0.097	63.55	0.172
17	76.45	0.0024	82.48	0.0175	95.74	0.093	60.32	0.144
18	76.31	0.0027	81.40	0.0176	95.19	0.098	67.30	0.160
19	74.41	0.0025	81.43	0.0177	90.62	0.031	63.27	0.187
20	79.58	0.0029	77.98	0.0177	95.70	0.112	62.88	0.164
21	77.55	0.0027	81.44	0.0178	94.77	0.103	61.26	0.158
22	74.85	0.0026	78.68	0.0173	95.00	0.106	63.54	0.190
23	78.78	0.0026	84.78	0.0174	98.54	0.085	77.96	0.132
24	82.60	0.0029	83.20	0.0176	98.68	0.074	70.07	0.182
25	81.31	0.0035	83.20	0.0176	99.63	0.117	65.50	0.178
26	77.61	0.0027	81.52	0.0177	99.00	0.093	67.50	0.156
27	79.81	0.0027	83.72	0.0177	99.12	0.117	62.28	0.194
28	79.58	0.0027	81.90	0.0178	99.46	0.098	65.10	0.155
29	73.10	0.0027	77.74	0.0178	88.25	0.108	53.87	0.191
30	74.10	0.0027	79.55	0.0176	90.45	0.102	60.80	0.157
Average	**77.22**	**0.00271**	**80.04933**	**0.022367**	**95.095**	**0.113897**	**64.86167**	**0.21873**

f_y =yield point, ε_y =yield point strain, f_{sh} =stress at onset of strain hardening, ε_{sh} = strain at onset of strain hardening, f_u=ultimate tensile strength, ε_u =strain at ultimate, f_f =stress at fracture point, ε_f = strain at fracture point

Table 3: Test results of tension tests on Grade 72.5 deformed bars #5 (16 mm) re-bars

Tests	f_y	ε_y	f_{sh}	ε_{sh}	f_u	ε_u	f_f	ε_f
1	70.97	0.0022	71.22	0.002	82.65	0.106	57.50	0.130
2	73.60	0.0025	76.91	0.024	90.93	0.073	60.65	0.106
3	70.48	0.0024	71.53	0.025	82.77	0.123	47.57	0.194
4	68.73	0.0024	68.65	0.023	81.65	0.140	76.76	0.221
5	70.45	0.0020	75.46	0.014	83.42	0.111	56.45	0.183
6	69.85	0.0023	75.40	0.015	83.60	0.116	56.33	0.170
7	71.96	0.0025	78.40	0.017	84.34	0.094	57.00	0.143
8	73.61	0.0022	73.50	0.011	84.56	0.137	60.48	0.218
9	69.73	0.0016	71.53	0.007	82.59	0.110	70.28	0.134
10	74.82	0.0024	75.24	0.004	91.22	0.163	75.68	0.265
11	75.40	0.0024	75.90	0.027	91.92	0.156	62.70	0.314
12	78.91	0.0024	84.94	0.011	92.28	0.089	63.13	0.136
13	73.34	0.0023	74.74	0.008	89.63	0.112	71.40	0.150
14	71.90	0.0020	76.78	0.009	87.86	0.118	57.20	0.112
15	74.97	0.0023	80.00	0.010	91.00	0.098	57.20	0.172
16	75.35	0.0023	81.48	0.010	90.61	0.099	60.80	0.158
17	73.30	0.0020	84.41	0.003	90.20	0.060	60.60	0.090
18	76.66	0.0024	85.78	0.003	92.47	0.060	58.26	0.087
19	69.43	0.0020	78.08	0.003	82.34	0.048	56.26	0.076
20	68.27	0.0015	78.36	0.003	81.73	0.053	55.18	0.076
21	75.55	0.0020	84.32	0.003	91.20	0.049	60.20	0.078
22	72.27	0.0020	78.21	0.003	83.75	0.053	56.96	0.078
23	73.83	0.0020	82.45	0.003	90.30	0.060	62.73	0.087
24	73.41	0.0020	82.35	0.003	90.47	0.053	60.00	0.084
25	75.38	0.0020	84.25	0.003	90.70	0.050	61.50	0.084
26	73.14	0.0020	73.54	0.003	84.70	0.050	55.96	0.074
27	73.84	0.0020	79.92	0.003	84.74	0.050	56.23	0.071
28	72.20	0.0020	80.67	0.003	88.65	0.066	60.60	0.090
29	69.50	0.0023	73.37	0.003	81.00	0.071	55.27	0.099
30	71.48	0.0020	77.36	0.003	83.90	0.077	57.72	0.106
Average	**72.7443**	**0.002144**	**77.83**	**0.008**	**86.906**	**0.088**	**60.29**	**0.132873**

f_y =yield point, ε_y =yield point strain, f_{sh} =stress at onset of strain hardening, ε_{sh} = strain at onset of strain hardening, f_u=ultimate tensile strength, ε_u =strain at ultimate, f_f =stress at fracture point, ε_f = strain at fracture point

Table 4: Average experimental control points for Grade 60 re-bars of #5(16 mm)

Point	Stress (ksi)	Strain (in/in)
1.Origin	**0**	**0**
2.Yield point f_y	77.22	0.00271
3. Onset of Strain hardening f_{sh}	80.05	0.02240
4. Ultimate Point f_u	95.10	0.11400
5. Fracture point f_r	64.86	0.21800

Table 5: Average experimental control points for Grade 72.5 re-bars of #5(16 mm)

Point	Stress (ksi)	Strain (in/in)
1.Origin	**0**	**0**
2.Yield point f_y	72.74	0.00214
3. Onset of Strain hardening f_{sh}	77.83	0.00840
4. Ultimate Point f_u	86.28	0.08800
5. Fracture point f_r	60.28	0.13300

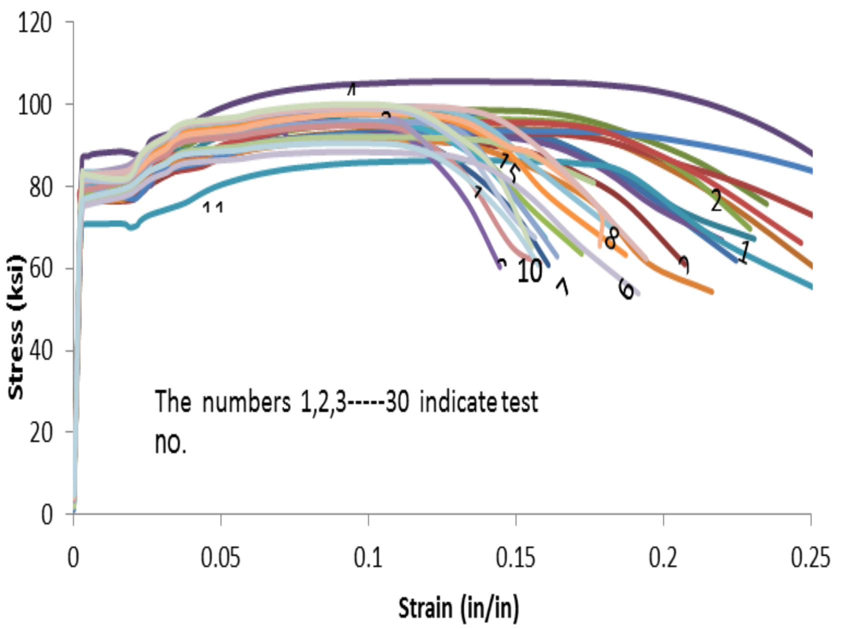

Fig. 1: Stress-strain curves for 30 samples of Grade 60 #5 (16 mm) re-bars

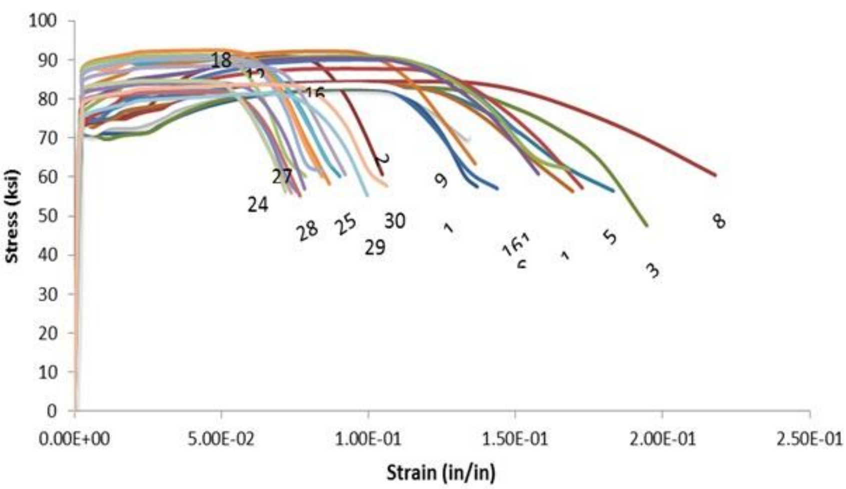

Fig. 2: Stress-strain curves for 30 samples of Grade 72.5 re-bars

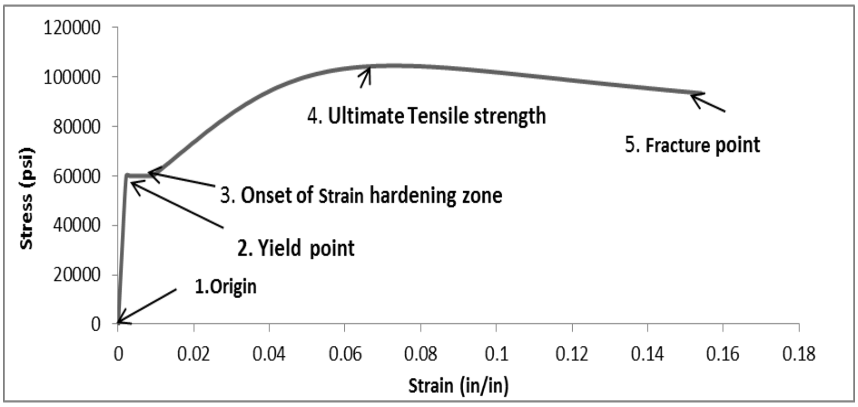

Fig. 3: Control points for an experimental average stress strain curve and idealized stress-strain

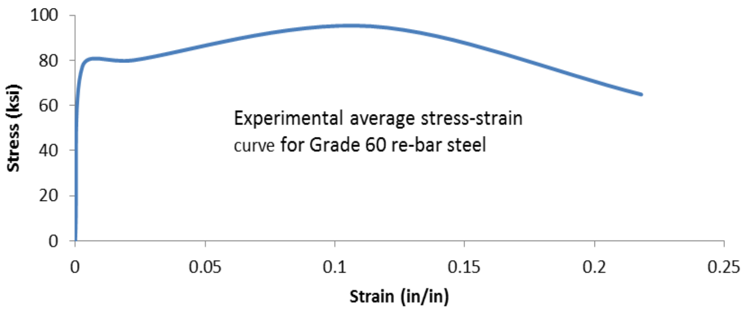

Fig.4: Experimental average stress-strain curve of Grade 60 #5 bars using control points of Table 4

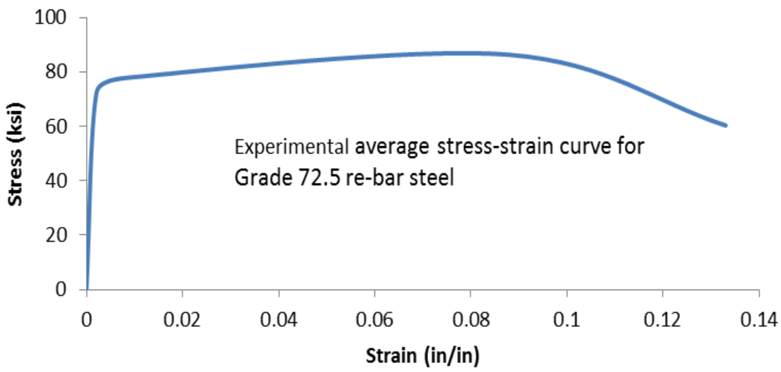

Fig. 5: Experimental average stress-strain curve of Grade 72.5 #5 bars using control points of Table 5

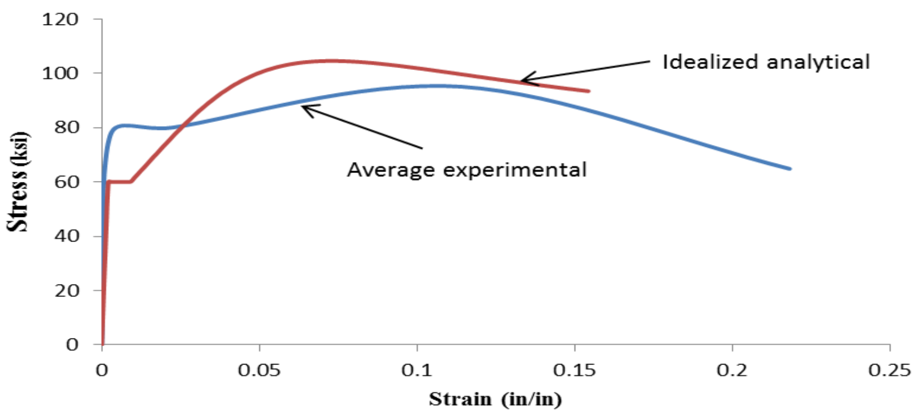

Fig. 6: Comparison of experimental average and idealized analytical stress-strain curve of Grade 60 re-bar

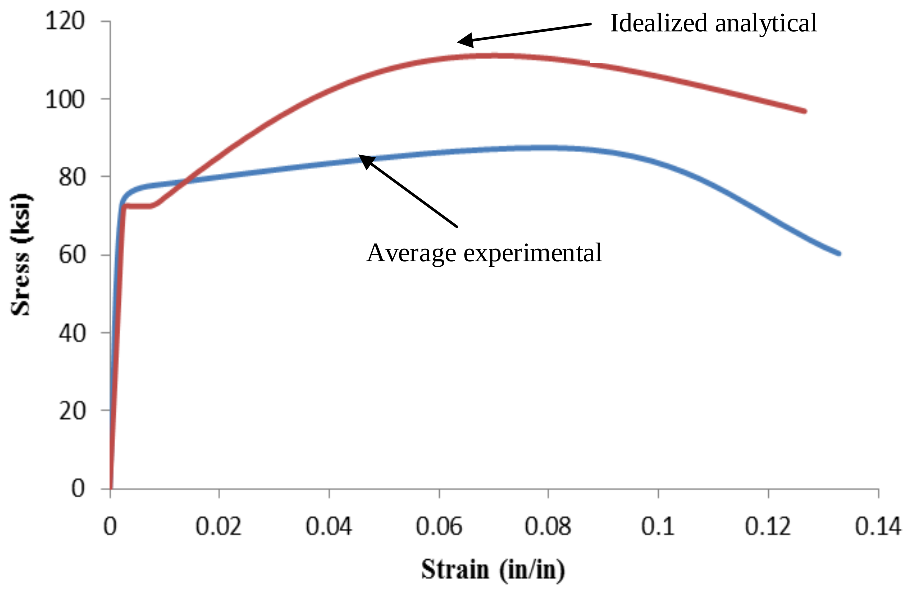

Fig. 7: Comparison of experimental average and idealized analytical stress-strain curve of Grade 72.5 re-bar

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