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Tensile strength behaviour of Thermo-mechanical treatment (TMT), Local and Imported Steel Rebar in Air.

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Abstract: *In this paper, the tensile strength of three sets of steel bar specimens which are the imported steel bars, locally manufactured steel bars from billets of recycled scraps and the locally produced steel bars from billets extracted from iron-ore and subjected to thermo-mechanical treatment (TMT) process were investigated. The results revealed degree of randomness of local bars to be almost twice those of the TMT and imported bars. The elongation of the TMT of 13.8% was the least of the three and did not satisfy the requirement for minimum elongation of 14%, whereas the elongation of the imported and local bars were 15.1% and 17.2% respectively meet the requirement of the minimum elongation. Coupled with its high ductility, local bars is just slightly higher in strength than mild steel. The tensile strength properties of steel bars in air and after immersion in liquids would inform engineers, infrastructure managers or client, professional organization and other stakeholders of the adequacy or limitations of the rebars types for structural engineering application. Also, the Standards Organization of Nigeria (SON) and other relevant professional bodies could work together to ensure improvement in the quality of materials supplied to building and civil engineering industries.*

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I. Introduction

The basic interest in the mechanical properties of steel has gained popularity in the construction industry since seventeen century that Galileo pioneered experimental work in elasticity which was later expanded in scope by the legendary Robert Hooke's (Harald et al. 2013; Yeon et al. 2007). Popular Hooke's law states that for an elastic material, the stress is directly proportional to the strain within the elastic limit. Also, the modulus of elasticity that is popularly known as the Young's modulus of elasticity was introduced in the early part of 1900s century and postulated that as far as a material is within its elastic, the ratio of stress-strain is a constant (Kayali and Zhu 2005; Phillips 1998). Reinforced concrete is a composite material made up of concrete and reinforcing bars (rebar), because concrete as a brittle material has very little tensile strength, which is an undesirable trait for a construction material (Basu et al. 2004; Castro et al. 2002). Rebar is added to concrete to increase ductility and to control crack widths. Whether the rebar is made of steel or fiber reinforced polymers, tensile stresses must be transferred from the concrete to the rebar (Chahrour and Soudk2005; Clifton et al. 1999). The transfer of stress from the concrete to the rebar is accomplished through bond between the two materials. A structure with sound analysis and design could still fail if the quality of the material used for the construction is poor (Ede 2000; Phillips 1998; NIS 1992). Statistics have shown that a significant number of structural failures can be attributed to poor material quality, influx of quacks and/or unethical professional practices, poor construction methodology, workmanship and unverified newly introduced reinforcement (Erhard 2006; Kosmatka et al. 2003). Though the two main materials used for constructional purposes in reinforced concrete structures are concrete and reinforcement steel bars. Achieving an acceptable probability that any designed structure would perform satisfactorily during their intended life is often hampered by non-compliance with structural design specifications and non-conformance of structural properties of materials used in the actual construction to the properties of materials specified at the designed stage (Kankam and Adom-Asamoah2002; Kaushik and Singh 2002; BS 4449, 2001). Thermo-mechanically treated (TMT) bars are products of an advanced heat treatment process in which hot bars coming out of last rolling mill stand are rapidly quenched through a series of water jets (Basu et al. 2004; Phillips 1998). This process provides intensive cooling of surface resulting in the bars having hardened surface with hot core and rebars are then allowed to cool in ambient conditions. During the slow cooling process, the heat released from core tempers the hardened surface, while core is turned into ferrite-pearlite aggregate composition. TMT process thus changes the structure of material to a composite structure of ductile ferrite pearlite composition with tough surface rim of tempered martensite providing an optimum combination of high strength, ductility, bendability and other desirable properties. To end with, the aim of this paper is to scrutiny steel bars that are rolled from billets that can be produced either from iron-ore through the blast furnace converter route, or by melting scraps and refining the same in the furnace.

II. Material And Methods

A total of 180 different steel specimens comprising conventional local, TMT and imported reinforcing bars each of 60 specimens from different sources in Lagos were investigated in the laboratory for tensile strength characteristics. The bar sizes considered were 10 mm, 12 mm, 16 mm, 20 mm and 25 mm throughout the study. The sample length and gauge length of each tested specimen in the universal testing machine were 600 mm and 100 mm respectively.

III. Result

3.1 Random analysis

The general parameters for local, TMT and imported (Ukraine) steel rebars are presented in Table 1.

Table 1. Statistical parameters for local, TMT and imported steel rebars.

Steel Types	Parameters	Yield strength (YS)	UTS (N/mm^2)	Stress ratio, $\frac{UTS}{YS}$	Elongation (%)
Local bars	Mean, μ (N/mm^2)	351.94	513.74	1.46	17.24
	SD, σ (N/mm^2)	42.61	70.38	0.15	3.11
	COV (%)	12.28	13.88	10.09	18.06
	μ + 1.64σ (N/mm^2)	421.65	628.97	1.71	22.35
	μ - 1.64 σ (N/mm^2)	282.24	398.48	1.21	12.13
	Range	224 - 432	371 - 636	1.15 – 1.90	8 - 22
TMT bars	Mean, μ (N/mm^2)	499.53	601.39	1.20	13.84
	SD, σ (N/mm^2)	33.48	50.32	0.07	2.29
	COV (%)	6.78	8.45	5.58	16.52
	μ + 1.64σ (N/mm^2)	554.26	683.75	1.32	17.58
	μ - 1.64 σ (N/mm^2)	444.87	519.10	1.09	10.09
	Range	401 - 561	483 - 686	1.03 – 1.35	10 - 20
Imported bars	Mean, μ (N/mm^2)	500.48	611.14	1.22	15.13
	SD, σ (N/mm^2)	31.09	59.02	0.11	2.06
	COV (%)	6.29	9.71	9.16	13.60
	μ + 1.64σ (N/mm^2)	553.28	709.43	1.40	18.50
	μ - 1.64 σ (N/mm^2)	459.64	524.81	1.04	11.76
	Range	430 – 560	500 – 884	1.03 – 1.77	12 – 23

From Table 1 that presented random analytical study of the rebar types irrespective of the bar size, Yield strength is the most sought-after tensile parameter, though other parameters such as ultimate tensile strength and elongation are of critical to determining the ductility, bendability and plasticity of the material. The characteristic yield strength is the steel reinforcing bar strength below which it is unlikely that more than 5 percent of the result did not fall within standard set by British standard code. This is essentially mathematically estimated as (μ - 1.64 σ), where μ and σ are the mean and standard deviation of the yield strength. The characteristic strengths of the local, TMT and imported rebars were 282.24 N/mm^2, 444.87N/mm^2 and 459.64N/mm^2, respectively. Coupled with its high ductility, local bars is just slightly higher in strength than mild steel. The degree of randomness of local bars is almost twice those of the TMT and imported bars. The elongation 17.24% and 15.13% of the local and imported bars respectively conform with the minimum value of 14% of BS 4449 (2001), while the TMT bars had a mean value of 13.84% which was less than the minimum requirement. The COVs of the elongation of the rebars in ascending order are 13.60%, 16.52% and 18.06% corresponding to the imported, TMT and local rebars.

3.2 Strength and elongation of bars

The stress- strain curve for local, thermo-mechanical treatment and imported steel bars are presented in Figure 1.

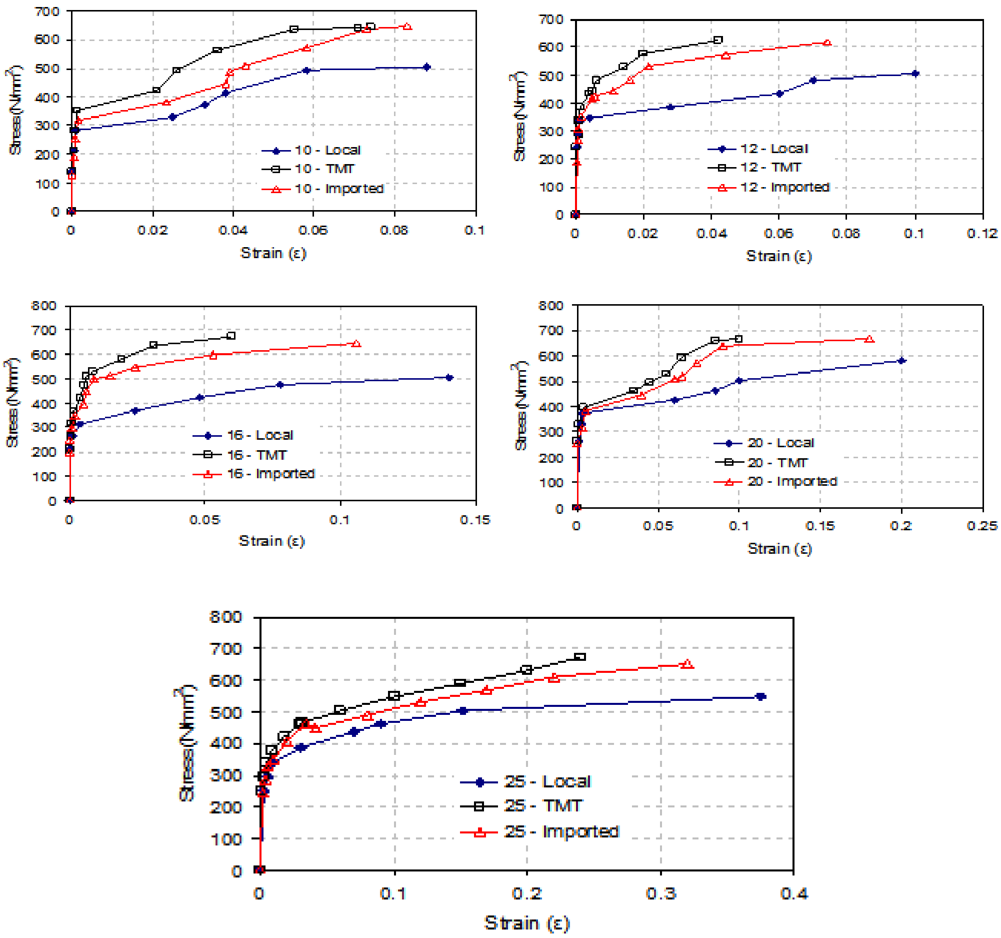

Figure 1. Typical stress-strain curve for the three rebar types for 10 mm, 12 mm, 16 mm, 20 mm and 25 mm.

Figure 1 reveals that yield strength (YS), ultimate tensile strength (UTS), Modulus of Elasticity (EM) and elongation of imported bars were 500 N/mm^2, 611 N/mm^2, 161 kN/mm^2, and 14% respectively, the local bars had 352 N/mm^2, 510 N/mm^2, 118 kN/mm^2, and 17% in the same order. Further experimental findings revealed that tensile strengths of most imported bars (YS > 460 N/mm^2) were enhanced as a result of the Thermo-Mechanical Treatment (TMT) they were subjected to at the expense of the EM (< 200 kN/mm^2). The YS, UTS and percentage elongation of local bars categorized in terms of the bar sizes were in the ranges 336.9 – 369.7 N/mm^2, 447.9 – 553.3 N/mm^2, and 16 – 18% respectively as shown in Table 1. 10 mm and 20 mm bar sizes had the minimum and maximum strengths respectively. The ratio of the ultimate strength to the yield strength value of the local bars, otherwise known as stress ratio, satisfied the minimum requirement value of 1.08 specified by BS 4449 (2001). The mean degrees of randomness or uncertainty measured as COV for strength and elongation were 12.5% and 17.7% respectively. The 12 mm and 25 mm bar sizes had the least and highest degree of uncertainties in strength respectively, while the COV of elongation measurement data for local bars was 10.4 – 23.7% with 16 mm and 25 mm bars having the least and the highest values.

The results of the tensile strength properties of TMT bars for YS, UTS and percentage elongation were in the ranges 481.5 – 508.0 N/mm^2, 582.9 – 621.5 N/mm^2, and 13.3 – 14.7% respectively. Contrary to the local bars, the minimum and maximum strengths of TMT bars correspond to 20 mm and 10 mm bar sizes respectively. All bar sizes except 12 mm did not satisfy the minimum stress ratio requirement value of 1.08 as specified by BS 4449 (2001). The mean degrees of randomness or uncertainty measured as COV for strength and elongation were 7.4% and 16.4% respectively. The 12 mm and 20 mm bar sizes had the least and highest degree of uncertainties in strength respectively, while the COV of elongation measurement data for local bars was 11.7 – 21.2% with 10 mm and 16 mm bars having the least and the highest degree of randomness.

The imported bars exhibited tensile strength properties in the ranges 470.8 – 531.8 N/mm^2, 591.3 – 626.4 N/mm^2, and 14.7 – 15.5% respectively. All bar sizes satisfied the minimum stress ratio requirement value of 1.08 as specified by BS 4449 (2001). The minimum and maximum strengths of the imported bars correspond to 10 mm and 25 mm bar sizes respectively. The mean degrees of randomness or uncertainty measured as COV for strength and elongation were 6.5% and 13.1% respectively. The 12 mm and 20 mm bar sizes had the least and highest degree of uncertainties in strength respectively, while the COV of elongation measurement data for local bars was 9.3 – 21.8% with 12 mm and 25 mm bars having the least and the highest degree of randomness. It can be concluded from Table 1 and Figure 1, that all the three steel rebar types met the requirements for the minimum stress ratio. However, it is obvious that though the tensile strengths of the TMT bars were comparably higher than the conventional local, it possessed the least plastic properties and hence elongation which was lower than the minimum requirement of most international standards. Imported and TMT bars had comparable COV in strength values, while the extent of uncertainties of local bars was almost twice the other two. Additionally, the degree of randomness both in terms of strength and elongation parameters was highest for the local bars and most reliable for the imported bars. Another fact observed from the study was the presence of voids in the sections of the local and TMT bars, most especially the large sizes.

3.3 Gaussian distribution

The Gaussian distribution for local, billet and imported (Ukraine) steel rebars are presented in Figure 2 and 3.

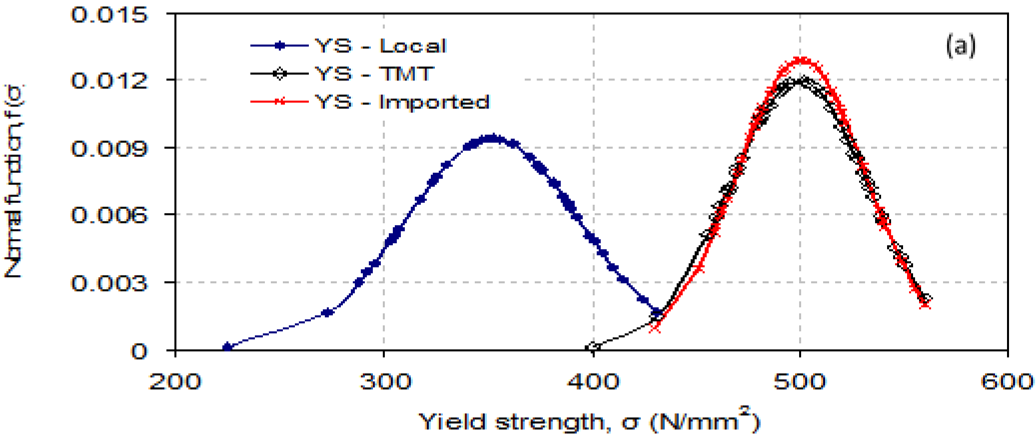

Figure 2. Gaussian (Normal) distribution for yield strength and stress ratio for local, TMT and imported steel rebars.

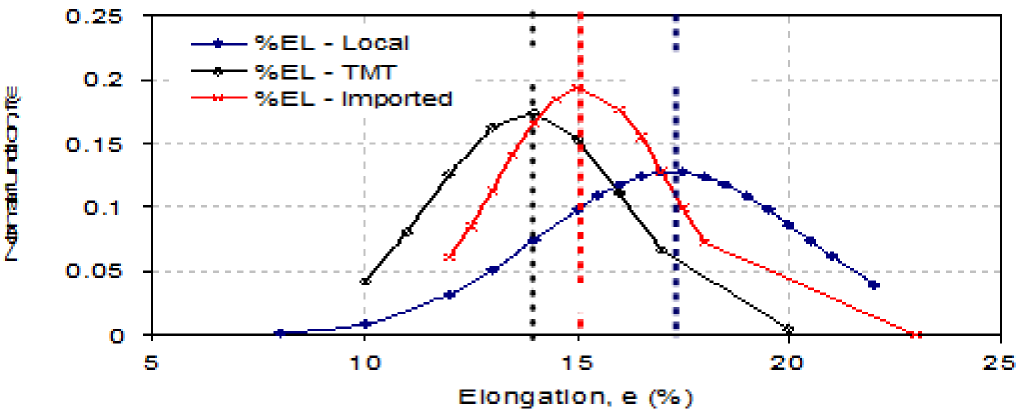

Figure 3. Gaussian (Normal) distribution for elongation of local, TMT and imported steel rebars.

Figure 2 and 3 shows the plot of the Gaussian (or Normal) distribution curves of the yield strength and stress ratio of the three rebar types. It is quite obvious that the results presented in plots confirm the results summary of Tables 1, the yield strengths and the stress ratios of TMT and imported steel rebars are comparable in values with a reasonably low degree of randomness or dispersion, while the tensile strength parameters of local bar are much remarkably different with higher degree of uncertainty (or higher degree of dispersion) than those of the local and TMT. Figure 2 also shows the Normal distribution curve of the percentage elongation of the three rebar types. The elongation of the TMT of 13.8% was the least of the three and did not satisfy the requirement for minimum elongation of 14%. The elongation of the imported and local bars were 15.1% and 17.2% respectively which meet the requirement of the minimum elongation requirements of 14% specified by the BS 4449 (2001).

IV. Conclusion

All the steel rebar types conformed to Normal (Gaussian) distribution. The characteristic strengths of the local, TMT and imported rebars were 282.2 N/mm^2, 444.8 N/mm^2 and 449.6 N/mm^2, respectively. Coupled with its high ductility, local bars is just slightly higher in strength than mild steel. The degree of randomness of local bars is almost twice those of the TMT and imported bars. The elongation 17.24% and 15.13% of the local and imported bars respectively conform with the minimum value of 14% of BS 4449 (2001), while the TMT bars had a mean value of 13.84% which was less than the minimum requirement. The COVs of the elongation of the rebars in ascending order are 13.6%, 16.5% and 18.1% corresponding to the imported, TMT and local rebars. Imported and TMT bars had comparable COV in strength values, while the extent of uncertainties of local bars was almost twice the other two. Additionally, the degree of randomness both in terms of strength and elongation parameters was highest for the local bars and most reliable for the imported bars. The YS, UTS, EM and elongation of imported bars were 500 N/mm^2, 601 N/mm^2, 161 kN/mm^2, and 13.8% respectively, the local bars had 352 N/mm^2, 510 N/mm^2, 118 kN/mm^2, and 17% in the same order. Further experimental findings revealed that tensile strengths of most imported bars (YS > 460 N/mm^2) were enhanced as a result of the Thermo-Mechanical Treatment (TMT) they were subjected to at the expense of the EM (< 200 kN/mm^2).

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