BONDING STRENGTH OF LOCALLY AND IMPORTED REBARS EMBEDDED IN REINFORCED CONCRETE, CASE STUDY SOUTH-WEST, NIGERIA.

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ABSTRACT

The limit of performance of the concrete structures reinforced with different types of steel bars in bonding is fundamental for both design and construction engineers as well as material scientist for improvement of material properties when necessary. It is obvious that in Lagos metropolis, the mean bar sizes for the different diameter of rebars considered for the imported are higher in diameter that the corresponding local types, with a very small margin. Also, there is a smaller degree of uncertainty in the imported reinforcing bars size having COV in the range of 0.06 to 0.20 and the local reinforcing bars in the range of 0.25 to 0.75 for the same diameter size range. The finding during random survey of steel rebars size distribution in Ibadan and indicated that the COV for imported steel falls within range 0.12 to 0.27, while the corresponding local steel was within the range of 0.19 to 0.812. The degree of uncertainty in bar sizes was smaller in Lagos than that of Ibadan. In addition, whereas the failure mode of the imported and TMT bars were either steel rupture (or steel breaking failure) or splitting failure, while the local bars failed by pull-out failure due to improper or inadequate bonding grip with concrete. TMT have almost exactly same bond strength values as the imported steel bars, while the local bars had 12% reduction in strength.

Keywords:

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INTRODUCTION

The basic interest in the mechanical properties of steel has gained popularity in the construction industry (Bellis 2011; Erhard 2006). In the seventeen century, Galileo pioneered experimental work in elasticity which was later expanded in scope by the legendary Robert Hooke's, which is the popular Hooke's law. The discovery is that for an elastic material, the stress is directly proportional to the strain within the elastic limit. Also, modulus of elasticity popularly known as the Young's modulus of elasticity was introduced in the early part of 1900s century and it postulated that as far as a material is within its elastic, the ratio of stress-strain is a constant (Chahrour and Soudki 2005; Kayali and Zhu 2005; Kosmatka et al. 2003; Clifton and Marthey 1983). Locally manufactured reinforcing steel bars from scrap metal are becoming very common in Nigeria in particular and Africa in general. In developing countries such as Nigeria where imported steel manufactured to world best standards is very expensive, milling companies and private individuals have taken up the challenge to re-cycle obsolete vehicle, machine metal parts and household metal waste for the production of structural and reinforcing steel (Balogh and Vigh 2013; Ede 2010; Basu et al. 2004). The typical of the registered indigenous steel rebar manufacturing industries that use scraps as their major raw materials for producing steel include Continental Iron and Steel Company (CISCO) Ikeja, Lagos, Universal Steel Company Ikeja, Lagos, Sun Flag Nigeria Ltd, Ikorodu, Lagos, Unique Steel Industres, Ltd, Lekki, Lagos, Nigerian Spanish Engineering Ltd, Kano, African Steel Nig. Ltd, Ikorodu, Lagos among several others. In fact, preliminary investigations revealed that there are scores of such local steel companies operating in Nigeria. In conclusion, the steel reinforcing bar required for structural concrete is partly produced by the country's inland rolling mills while the balance is sourced through import. The importation is carried out mostly by private entrepreneurs and the quality of such imported product is not always guaranteed as they are essentially brought in from different sources without any thorough standardization process regarding their structural properties (Kankam and Adom-Asamoah 2002; Logan 2000; Phillips 1978). Hence, differences are bound to arise in the strengths, and possibly, geometry of steel assumed in design and those used for actual construction, unless tests are carried out on every batch of imported steel delivered on construction site (Phillips 1998; Neville and Brooks 1994). With the near collapse of the government-owned rolling mills and dwindling performance of the privatized counterparts in an unfriendly economy, influx of steel rebars from questionable sources are the order of the day in Nigerian markets.

METHODS

The method used in carrying out this research work is field survey and laboratory tests. Field survey which includes statistical evaluation of size distributions of both imported and local steel rebars. Compression test was carried out on the concrete to determine the behavior of such concrete under compressive loads of concrete beams reinforced with steel rebar types.

Results and Discussions

Dispersion degree

The degree of uncertainty in the geometric size of local bars was six times higher than the imported. It is obvious that in Lagos metropolis, the mean bar sizes for the different diameter of rebars considered for the imported are higher in diameter that the corresponding local types, with a very small margin. Also, there is a smaller degree of uncertainty in the imported reinforcing bars size having COV in the range of 0.06 to 0.20 and the local reinforcing bars in the range of 0.25 to 0.75 for the same diameter size range. The finding during random survey of steel rebars size distribution in Ibadan and indicated that the COV for imported steel falls within range 0.12 to 0.27, while the corresponding local steel was within the range of 0.19 to 0.812. The degree of uncertainty in bar sizes was smaller in Lagos than that of Ibadan. However, if we have to consider the sizes of steel made with imported billet and thermo mechanically treated (TMT product), the degree of uncertainty is almost the same.

Direct tension

The reinforcing bar subject to direct tension must be firmly anchored if it is not to be pulled out of the concrete. Bars subjected to forces induced by flexure must similarly be anchored to develop their design stresses. The anchorage depends on the bond between the bar and the concrete, and the area of contact. The bond strength of various steel rebar types of size 12 mm and 16 mm embedded in a 150 mm diameter concrete cylinders of lengths 300 mm, 550mm and 700 mm with a corresponding embedment or anchorage lengths 150 mm, 477 mm and 635.6 mm respectively. As shown in Figure 1, the minimum anchorage or embedment length, L is required to prevent the pull out of any reinforcing bar of size φ. Considering the forces on the bar, the tensile pull-out force, F_t and the anchorage force, F_s are given by:

$$F_t = \frac{\pi\phi^2}{4} f_s \quad . \quad . \quad 1$$

$$F_s = f_{bu} L_b \pi\phi \quad . \quad . \quad 2$$

To satisfy equilibrium condition at ultimate, the ultimate shear or anchorage force must be equal to the direct tensile force acting in the reinforced concrete element.

$$P = F_t = F_s \quad . \quad . \quad . \quad 3$$

$$P_u = \frac{\pi\phi^2}{4} f_s = f_{bu} L_b \pi\phi \quad . \quad . \quad 4$$

The anchorage length, L_b is estimated as:

$$L = \frac{f_s}{4 f_{bu}} \phi = \frac{0.95 f_y}{4 f_{bu}} \phi \quad . \quad . \quad 5$$

where f_{bu} and f_s are the ultimate anchorage bond stress and the direct tensile stress in the bar during pull-out test.

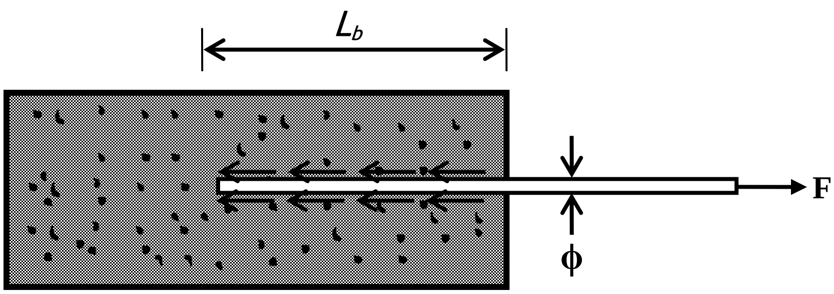

Figure 1. Experimental setup for bond strength test using pull-out method

Experimentally, the bond strength can be estimated as:

$$f_{bu} = \frac{P_u}{L_b \pi \phi} \quad . \quad . \quad . \quad . \quad 6$$

BS 8110 – 1 (2002) specifies the design ultimate anchorage bond stress, f_{bu}, as

$$f_{bu} = \beta \sqrt{f_{cu}} \quad . \quad . \quad . \quad . \quad 7$$

where bond coefficient β for the type 2 – deformed bar, according to BS 8110 – 1 (2002), is 0.50.

The bond strength from the experimental results using pull-out method and the BS 8110-1 (2002) are summarized in Tables 1-4 and graphically compared in Figure 2. Cases I and III represent the specimens prepared in line with the requirements of BS 8110 - 1(2002) for 16 mm and 12 mm bar diameters, while Cases II and IV correspond to the specimens prepared in line with conventional rule-of-thumb for the 16 mm and 12 mm bar sizes. These results were compared with the ultimate design bond strength value of 2.40 N/mm^2 in line with equation 7. It is very obvious from the plots and the Tables that Cases II and IV would always give unreasonably higher estimation of the bond strength than the design bond strength value and should be discouraged in laboratories, while Cases I and III gave reasonable results

comparable with the requirements. However, it can be concluded that local bars had the lowest bond strength values with the highest degree of dispersion or randomness as indicated by the COV. This can be explained by the smallest rib geometry which ensures proper bonding with the host concrete. In addition, whereas the failure mode of the imported and TMT bars were either steel rupture (or steel breaking failure) or splitting failure, while the local bars failed by pull-out failure due to improper or inadequate bonding grip with concrete. In addition, it is ideal that the design value be less than the measured bond strength at failure. Referring to the bond strength value for 16 mm and 12 mm bars embedded in concrete and normalized with the imported value and conducted in line with the British Standards, TMT have almost exactly same bond strength values as the imported, while the local bars have 12% reduction in strength. Likewise, as further shown in Tables 1 and 4 corresponding to Cases I and III, the pull-out length at failure of imported and TMT bars are comparable, while the local bars were about 10% higher. The spread of dispersion of the pull-out length at failure measured in terms of the COV shows that the degree of randomness of TMT and local bars were 18% and 27% higher than those of the imported steel bars.

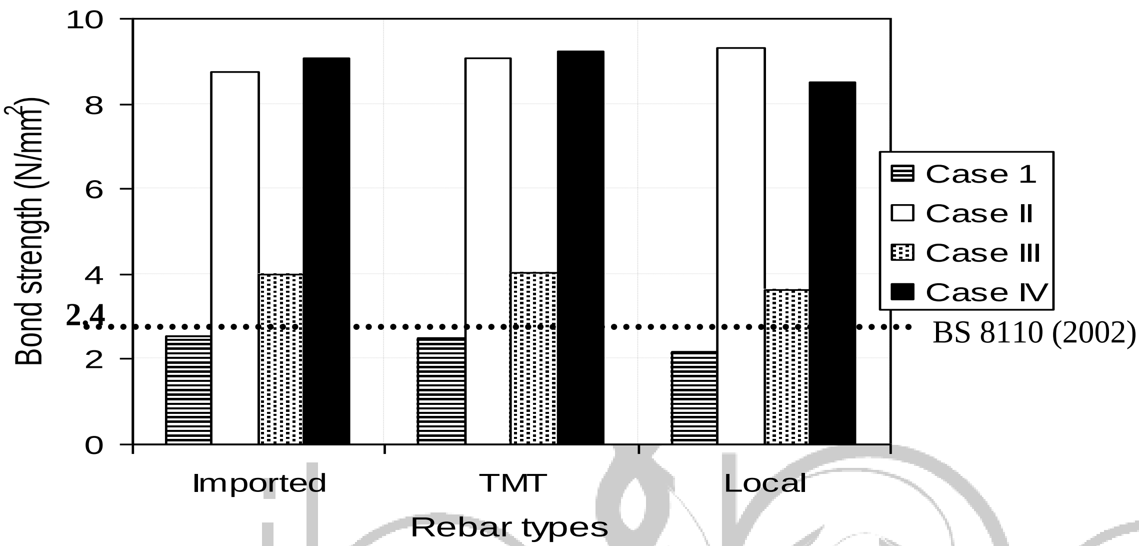

Figure 2. Bond strength of steel rebars embedded in concrete cylinders

Table 1. Bond strength of steel rebars embedded in concrete – Case I

Bar size, ϕ = 16 mm, Concrete diameter = 150 mm, Concrete length = 700 mm, Embedment length, L_b = 635.64 mm, f_{cu} = 20 N/mm^2

		Yield load P (kN)	Ultimate load P_u (kN)	Failure mode	Pull-out Length, (mm)	Bond stress, f_b (N/mm^2)	Ultimate bond strength, f_{bu} (N/mm^2)	Design bond strength, f_{bu} (N/mm^2)
Imported	Mean, μ	71.67	81.83	SF/BF	18.00	2.24	2.56	2.24
	SD, σ	1.63	1.83		3.16	0.05	0.06	
	COV (%)	2.28	2.24		17.57	2.28	2.24	
TMT	Mean, μ	69.83	80.33	SF	17.50	2.19	2.51	2.24
	SD, σ	1.17	1.51		4.18	0.04	0.05	
	COV (%)	1.67	1.87		23.90	1.67	1.87	
Local	Mean, μ	52.78	68.89	PF	21.67	1.65	2.16	2.24
	SD, σ	5.36	10.58		3.54	0.17	0.33	
	COV (%)	10.15	15.35		16.32	10.15	15.35	

Note:
BF: Steel breaking failure; SF: Splitting failure; PF: Pull-out failure

Table 2. Bond strength of steel rebars embedded in concrete – Case II

Bar size, ϕ = 16 mm, Concrete diameter = 150 mm, Concrete length = 300 mm, Embedment length, L_b = 150 mm, f_{cu} = 20 N/mm^2

		Yield load P (kN)	Ultimate load P_u (kN)	Failure mode	Pull-out Length, (mm)	Bond stress, f_b (N/mm^2)	Ultimate bond strength, f_{bu} (N/mm^2)	Design bond strength, f_{bu} (N/mm^2)
Imported	Mean, μ	44.50	66.00	SF	15.83	5.90	8.75	2.24
	SD, σ	1.05	2.28		4.92	0.14	0.30	
	COV (%)	2.36	3.46		31.05	2.36	3.46	
TMT	Mean, μ	56.50	68.50	SF	18.33	7.49	9.09	2.24
	SD, σ	2.43	5.36		4.08	0.32	0.71	
	COV (%)	4.30	7.82		22.27	4.30	7.82	
Local	Mean, μ	58.33	70.22	PF	16.33	7.74	9.31	2.24
	SD, σ	4.24	5.83		13.44	0.56	0.77	
	COV (%)	7.27	8.30		82.26	7.27	8.30	

Note:
BF: Steel breaking failure; SF: Splitting failure; PF: Pull-out failure

Table 3. Bond strength of steel rebars embedded in concrete – Case III

Bar size, ϕ = 12 mm, Concrete diameter = 150 mm, Concrete length = 550 mm, Embedment length, L_b = 476.73 mm, f_{cu} = 20 N/mm^2

		Yield load P (kN)	Ultimate load P_u (kN)	Failure mode	Pull-out Length, (mm)	Bond stress, f_b (N/mm^2)	Ultimate bond strength, f_{bu} (N/mm^2)	Design bond strength, f_{bu} (N/mm^2)
Imported	Mean, μ	70.33	71.67	SF	16.17	3.91	3.99	2.24
	SD, σ	2.16	2.50		3.19	0.12	0.14	
	COV (%)	3.07	3.49		19.72	3.07	3.49	
TMT	Mean, μ	67.83	72.50	SF	16.17	3.77	4.03	2.24
	SD, σ	1.94	3.02		3.25	0.11	0.17	
	COV (%)	2.86	4.16		20.11	2.86	4.16	
Local	Mean, μ	58.44	65.44	PF	15.67	3.25	3.64	2.24
	SD, σ	7.76	6.19		4.85	0.43	0.34	
	COV (%)	13.28	9.45		30.94	13.28	9.45	

Note:
BF: Steel breaking failure; SF: Splitting failure; PF: Pull-out failure.

Table 4. Bond strength of steel rebars embedded in concrete – Case IV

Bar size, ϕ = 12 mm, Concrete diameter = 150 mm, Concrete length = 300 mm, Embedment length, L_b = 150 mm, f_{cu} = 20 N/mm^2

		Yield load P (kN)	Ultimate load P_u (kN)	Failure mode	Pull-out Length, (mm)	Bond stress, f_b (N/mm^2)	Ultimate bond strength, f_{bu} (N/mm^2)	Design bond strength, f_{bu} (N/mm^2)
Imported	Mean, μ	54.26	68.50	SF	11.17	7.20	9.09	2.24
	SD, σ	3.98	5.13		2.99	0.53	0.68	
	COV (%)	7.34	7.49		26.82	7.34	7.49	
TMT	Mean, μ	60.33	69.67	SF	11.67	8.00	9.24	2.24
	SD, σ	11.27	8.29		2.58	1.50	1.10	
	COV (%)	18.68	11.89		22.13	18.68	11.89	
Local	Mean, μ	51.36	64.11	PF	11.11	6.81	8.50	2.24
	SD, σ	5.28	5.51		2.32	0.70	0.73	
	COV (%)	10.27	8.59		20.84	10.27	8.59	

Note:
BF: Steel breaking failure; SF: Splitting failure; PF: Pull-out failure.

CONCLUSION

The degree of uncertainty in the geometric size of local bars was six times higher than the imported. It is obvious that in Lagos metropolis, the mean bar sizes for the different diameter of rebars considered for the imported are higher in diameter that the corresponding local types, with a very small margin. Also, there is a smaller degree of uncertainty in the imported reinforcing bars size having COV in the range of 0.06 to 0.20 and the local reinforcing bars in the range of 0.25 to 0.75 for the same diameter size range. The finding during random survey of steel rebars size distribution in Ibadan and indicated that the COV for imported steel falls within range 0.12 to 0.27, while the corresponding local steel was within the range of 0.19 to 0.812. The degree of uncertainty in bar sizes was smaller in Lagos than that of Ibadan. However, if we have to consider the sizes of steel made with imported billet and thermo mechanically treated (TMT product), the degree of uncertainty is almost the same. Local bars had the lowest bond strength values with the highest degree of dispersion or randomness due to its small rib geometry which did not ensure proper bonding with the host concrete. In addition, whereas the failure mode of the imported and TMT bars were either steel rupture (or steel breaking failure) or splitting failure, while the local bars failed by pull-out failure due to improper or inadequate bonding grip with concrete. TMT have almost exactly same bond strength values as the imported steel bars, while the local bars had 12% reduction in strength. Likewise, the pull-out length at failure of imported and TMT bars are comparable, while the local bars were about 10% higher. The spread of dispersion of the pull-out length at failure measured in terms of the COV shows that the degree of randomness of TMT and local bars were 18% and 27% higher than those of the imported steel bars.

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