STRENGTH, DUCTILITY AND CHEMICAL PROPERTIES OF REINFORCING STEEL BARSIN GHANA'S BUILDING CONSTRUCTION INDUSTRY

Abstract

The steel manufacturing industry in Ghana has grown rapidly in the last decade. Local steel milling companies are taking advantage of the readily available scrap metals as raw material to produce reinforcing bars. Major steel importers also continue to import reinforcing bars into the country to fill the gap between production and demand of steel reinforcing bars in Ghana. The question of whether these locally milled and imported reinforcing bars meet internationally accepted standards remains unanswered. This research investigated the mechanical and chemical properties of reinforcing bars available in the Ghanaian market.A total of 700 samples of 12mm-25mm nominal diameter reinforcing steel bars were collected from three major steel bar distributors and construction sites in Accra. The reinforcing bars sampled represented steel bars from four local milling companies and imported steel from Ukraine. Yield strength and maximum tensile strength of mild steel reinforcing bars milled in Ghana ranged from 328.26 N/mm^2 to 487.41 N/mm^2 and 487.41 N/mm^{2}to598.42 N/mm^2 respectively. Moreover the high yield reinforcing bars recorded yield strength ranging from 341.93 N/mm^2 to 702.83 N/mm^2 and tensile strength ranging from 497.36 N/mm^2 to 815.67 N/mm^2. All the reinforcing bars recorded carbon contents higher than the maximum requirement of 0.24% by BS4449:2005+A2:2009 and 0.22-0.32% by GS [1] specification. The local milling companies need to improve on the milling process to remove excess carbon from the steel bars in order to improve on ductility.

Key Words;*Reinforcing bars, steel, ductility, yield strength, chemical composition, scrap metals*

1. Introduction

The usefulness of any engineering material is dependent on its properties. Mechanical and chemical properties of reinforcing bar which is one of the most important structural engineering materials cannot be over- emphasized. Chemical compositions of reinforcing bars contribute to the strength, hardness, toughness and ductility of the steel bars [2]. While carbon contributes to the strength of the steel bars, excess composition of carbon turns to make the reinforcing bars brittle. Mechanical properties such as yield and tensile strength are the main properties considered when choosing steel bars as reinforcement material.

The construction industry in Ghana in terms of Distribution of Gross Domestic Product (at Basic Prices) was averagely 7.1 % to 9.1 % of DGP from 2013 to 2018, according to annual gross domestic product report of April 2019 [3]. The industry depends heavily on steel which is one of the essential construction materials worldwide. Steel production and importation have equally grown significantly over the last decade in Ghana. Steel producing companies have taken advantage of the high demand for reinforcing bars and are producing steel bars from scrap metals which are readily available in the country. The local milling companies have started producing high yield (high tensile strength) reinforcing bars which was not the case previously. The main steel distribution companies are also importing a lot of reinforcing bars into the country. Both the imported and locally milled rebars are readily available in the open market for any client to buy and use for civil engineering structures. Locally milled mild steel bars are ribbed bars with ribs and lugs to improve on bonding with concrete.

Selection of rebars as structural engineering material depends on factors including: maximum tensile strength, yield strength, toughness and ductility, availability and cost and specification and code/s adopted [2]. This research investigated the mechanical and chemical properties of these reinforcing bars available in the local market.

The structural engineer may focus on the yield and tensile properties of the steel bars in the market, but ductility is equally important for effective performance of the rebars under loading. Ductility is the measure of the ability of a material to sustain plastic deformations before collapse [4].

The BS 4449:2005 +A2:2009 requirement for minimum elongation at maximum force for a class C reinforcement steel bars is 7.5% asshown in Table 1. The GS 778-2:2018 [3] also specifies the minimum total elongation at fracture of 14% for Class B400C-B550C reinforcement bars in Ghana. The steel bars belonging to the above class are required to have minimum Tensile to Yield strength ratio (R_m/R_{eH}) of 1.15.

Table 1: Characteristic tensile properties of steel bars [1]

	Yield Strength R_{eH} N/mm^2	Tensile/Yield strength ratio R_m/R_{eH}	Total elongation at max force, A_{gt} (%)
500A	500	1.05	2.5
500B	500	1.08	5.0
500C	500	≥1.15, <1.35	7.5

GS 788-2:2018[3]specifies the minimum yield strength requirement for reinforcement steel bars as 300 N/mm^2, however no upper limit was specified for steel bar in the class B300A – B550C by the GS 788-2:2018. Moreover steel bars in ductility class "D" are required to have the maximum yield strength of 1.3 x R_{eH}(min.), that is 30% more of the minimum yield strength.

2. Laboratory Experiment

A total of 700 reinforcing steel bar specimens were selected from four local milling companies namely Ferro Fabrik Limited, Sentuo Steel Limited, FabrimetalLimited and United steel and one foreign manufacturing company in Ukraine (Arcelor Mittal). Mechanical properties of the steel bars were tested using an Automatic Universal Tensile and Compression machine (PROETI 2000 kN). Specimens tested were 12mm to 32mm nominal diameter. Sample were selected over the period of six month to ensure that reinforcing bars collected fairly represent different casts from the manufacturing companies.

The samples used for tensile strength test were selected fromfour samples collected every month. Out of the four samples, one was randomly selected each month making a total of six samples each for the period of six months. A total of 3 randomly sampled reinforcing steel bars of sizes mentioned above were subjected to laboratory testing using a tensile strength testing machine. The 3 samples were randomly selected from the pool of six (6) pieces of each size drawn from a bigger poll of twenty-five (25) samples collected in six months. These sample were collected from the major steel distributors in Accra, Ghana.

Chemical composition analysis was conducted on samples of reinforcing bar using the Scanning Electron Microscope Energy dispersive X-ray (SEM Edx) method.A total of 8 specimens were examined for their chemical composition. Two samples each of reinforcing bars were taken from every manufacturer. One sample from the mild steel category and the other from the high yield category. However, United steel company did not have high yield reinforcing bars in the market,while imported reinforcing steel bars1 were only in high yield category. Figure 1shows typical specimens of reinforcing steel bars."FFL" represents steel bar from Ferro Fabrik Limited, "FAB" for Fabrimetal Limited, "STS" for Sentuo Steel Limited and "IMP" for Arcelor Mittal steel in that order.

Fig 1: Typical samples of reinforcing steel bars in Ghana

3. Results

3.1 Tensile Properties

Analysis of the results shows that the minimum yield strength for mild steel reinforcing bars was 328.26 N/mm^2 obtained by United Steel Ltd. The maximum yield strength of 487.41N/mm^2 was obtained by Ferro Fabrik Ltd. The mean yield strength for mild steel rebars was 395.09N/mm^2. Minimum and maximum tensile strength for mild steel reinforcement bar of 487.41 N/mm^2 and 598.42 N/mm^2 were obtained by United Steel Ltd and Fabrimetal Ltd, respectively. The mean tensile strength was 520.01 N/mm^2.

High yield reinforcement bars had yield strength ranging from 341.93 N/mm^2 to 702.83 N/mm^2 with mean value of 572.87 N/mm^2. The highest yield strength was recorded by imported steel bar from Arcelor Mittal of Ukraine.Minimum and maximum tensile strength for high yield reinforcement bar of 497.36 N/mm^2 and 815.67 N/mm^2 was obtained by Sentuo Steel Ltd and Imported Steel respectively. The mean tensile strength was 707.89 N/mm^2.

3.2 Chemical Properties

Mild steel reinforcing bars milled by local milling companies recorded an average carbon content of 2.11%. The actual values ranged from 1.165 to 3.183%. Other constituents such are Nitrogen and Fluorine were present in appreciable proportion in two of the mild steel reinforcing bars. In the category of high yield reinforcing bars, all the local companies examined recorded more than

4.0% of carbon content while imported high yield reinforcing bar recorded 1.845% of carbon content. The mean carbon content of high yield steel bars was 5%.None of the steel reinforcing bars examined met the carbon content specification of 0.24% as specified by BS4449:2005+A2:2009. Steel reinforcing bars from one company had almost all chemicalsconstituent evaluated present in the steel bars while other companies have four or more chemical constituents. Table 2 shows the carbon composition of the reinforcing bars from the various companies.

Table 2 Chemical composition of reinforcing bars in the Ghanaian market

Percentage Average Weight Chemical Concentration of Reinforcement Bars																
Bar ID	**Bar Type**	**O**	**C**	**Fe**	**N**	**Cl**	**Si**	**Al**	**Ca**	**Na**	**Mg**	**S**	**K**	**F**	**Cr**	**Mn**
FFL	Mild Steel	8.56	1.54	89.43	-	-	-	-	-	-	-	-	-	-	0.09	0.38
USC	Mild Steel	2.47	1.17	95.79	-	-	0.15	0.03	-	-	-	-	-	-	-	0.41
FAB	Mild Steel	8.58	2.54	85.02	1.03	0.16	0.18	0.10	0.06	0.06	0.06	0.03	-	1.92	0.05	0.22
STS	Mild Steel	4.64	3.18	90.59	-	-	-	-	-	-	-	-	-	1.26	-	0.33
FFL	High Yield	16.06	4.49	79.02	-	-	0.20	0.14	-	-	0.09	-	-	-	-	-
IMP	High Yield	6.72	1.85	91.09	-	-	-	-	-	-	-	-	-	-	-	0.35
FAB	High Yield	6.72	9.35	80.42	2.49	0.07	0.13	0.06	0.12	0.23	0.02	0.07	0.06	-	-	0.28
STS	High Yield	3.86	4.21	91.02	0.93	-	-	-	-	-	-	-	-	-	-	-

KEY

FFL= Ferro Fabrick Ltd

USC=United Steel Ltd

IMP=Imported Steel

FAB=Fabrimetal Limited

STS=Sentuo Steel Limited

4. Discussion of Results

4.1 Yield and tensile strength of steel rebars

Mildsteel reinforcing bars produced in Ghana can be classified as medium to high strength (high yield) steel. The steel bars designated as mild steel bars recorded yield strength ranging from 328.26 N/mm^2 to 487.41 N/mm^2 and maximum tensile strength between 487.41 N/mm^2 and 598.42 N/mm^2 using their nominal diameters to calculate the cross sectional areas of the reinforcing bars. This confirmed an earlier research [5] which put the mild steel bars in Ghana into a category of medium strength steel bars.

High yield reinforcing bars produced in Ghana are designated as having characteristic strength of 500N/mm^2 by the local milling companies. Moreover the rebars recorded yield strength ranging from 341.93 N/mm^2 to 702.83 N/mm^2 and tensile strength ranging from 497.36 N/mm^2 to 815.67 N/mm^2 when tested. The lowest yield and maximum tensile strength of 341.93 N/mm^2 and 497.36 N/mm^2 respectively were recorded by 16mm nominal diameter rebars from Sentuo Steel Limited. The maximum tensile strength of 497.36 N/mm^2 however met the minimum requirement of 485N/mm^2 of BS4449:2005+A2:2009 for deformed reinforcement bars for concrete. The maximum tensile stress of 815 N/mm^2 recorded by 16mm nominal diameter reinforcing bars from Fabrimetal Limited was highly beyond the absolute maximum limit of 650 N/mm^2 stated by the BS4449:2005+A2:2009.

Table 3: Mechanical Properties of Mild Steel bars in the Ghanaian market

Bar Source/ID	**Bar Type**	**Bar Size (mm)**	**Yield Stress (f_y) N/mm^2**	**Yield Strain (E_y)**	**Max Stress (f_{max}) N/mm^2**	**Ultimate Stress (f_{ult}) N/mm^2**	**Total Elongation (%)**
FFL 12R	Mild Steel	12.00	464.20	0.0026	545.19	457.57	18.03
USC 12R	Mild Steel	12.00	353.68	0.0022	499.57	371.36	25.54
FAB 12R	Mild Steel	12.00	457.57	0.0031	538.30	413.36	18.70
STS 12R	Mild Steel	12.00	362.52	0.0020	499.57	465.97	26.00
FFL 16R	Mild Steel	16.00	487.41	0.0029	527.20	363.07	12.79
USC 16R	Mild Steel	16.00	328.26	0.0020	487.41	447.62	22.97
FAB 16R	Mild Steel	16.00	412.81	0.0025	512.28	437.68	20.04
STS 16R	Mild Steel	16.00	343.18	0.0020	522.23	467.52	27.14
USC 20R	Mild Steel	20.00	331.04	0.0020	496.56	432.90	22.79
FAB 20R	Mild Steel	20.00	474.28	0.0024	598.42	509.29	20.64
STS 20R	Mild Steel	20.00	331.04	0.0019	493.38	448.82	24.66

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FAB=Fabrimetal

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Fig. 2 Stress-Strain plot of 12mm nominal diameter mild steel ribbed reinforcing bars

Fig. 3 Stress-Strain plot of 16mm nominal diametermild steel ribbed reinforcing bars

Fig. 4 Stress-Strain plot of 20mm nominal diametermild steel ribbed reinforcing bars

Analysis of the various steel bars revealed that average total elongation ranges from 12.79% to 27.14% as detailed in Table 3. Reinforcing steel from Sentuo Steel Company recorded the longest total elongation in all the categories of mild steel bars sampled. Moreover reinforcing steel bars from United Steel Company produced relatively lower yield stress than other steel bars in the Ghanaian steel market. The average yield strength ranges from 328.26 N/mm^2 to 487.41 N/mm^2 and maximum tensile strength from 487.41 N/mm^2 to 598.42 N/mm^2 for mild steel bars. Steel bars of nominal diameter 16mm produced by Fabrimetal limited recorded the highest yield stress of 487.41 N/mm^2

whereas steel bars of the same diameter from United Steel Company recorded 328.26 N/mm^2 as the lowest yield stress. Even though reinforcing steel bars from Ferro Fabrik Limited turn to have higher yield and maximum tensile stresses, they also recorded lower total elongation as shown by Fig. 2 and 3. However, 20mm diameter reinforcing steel from Fabrimetal limited recorded the highest yield and maximum tensile stresses of 474.28 N/mm^2 and 598.42 N/mm^2 respectively as detailed in Fig. 4

Table 4: Mechanical Properties of High Yield Reinforcement Bars in Ghana

Bar Source/ID	**Bar Type**	**Bar Size (mm)**	**Yield Stress (f_y) N/mm^2**	**Yield Strain (E_y)**	**Max Stress (f_{max}) N/mm^2**	**Ultimate Stress (f_{ult}) N/mm^2**	**Total Elongation (%)**
FFL 12Y	High Yield	12.00	636.62	0.0032	747.14	557.04	10.68
IMP 12Y	High Yield	12.00	674.20	0.0036	760.41	497.36	10.62
FAB 12Y	High Yield	12.00	636.62	0.0032	751.56	557.04	11.60
STS 12Y	High Yield	12.00	506.20	0.0026	751.56	716.20	18.19
FFL 16Y	High Yield	16.00	576.94	0.0030	616.72	452.60	11.92
IMP 16Y	High Yield	16.00	482.44	0.0026	606.78	358.10	13.57
FAB 16Y	High Yield	16.00	696.30	0.0036	815.67	586.88	10.52
STS 16Y	High Yield	16.00	341.93	0.0018	497.36	397.89	26.86
FFL 20Y	High Yield	20.00	557.04	0.0029	649.35	477.46	14.09
IMP 20Y	High Yield	20.00	588.87	0.0032	741.98	502.93	12.77
FAB 20Y	High Yield	20.00	490.20	0.0030	708.56	525.21	14.05
FFL 25Y	High Yield	25.00	570.41	0.0030	723.20	560.22	19.02
IMP 25Y	High Yield	25.00	702.83	0.0037	790.43	631.53	13.63

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Fig. 5 Stress-Strain plot of 12mm nominal diameterhigh yield reinforcing bars

Fig. 6 Stress-Strain plot of 16mm nominal diameterhigh yield reinforcing bars

Fig. 7 Stress-Strain plot of 20mm nominal diameterhigh yield reinforcing bars

Fig. 8 Stress-Strain plot of 25mm nominal diameterhigh yield reinforcing bars

Average yield stress for reinforcing steel bars designated as high yield rebars in Ghana ranged from 341.93N/mm^2 to 702.83 N/mm^2. Rebar of 16mm nominal diameter produced by Sentuo Steel Company recorded the minimum yield stress of 341.93 N/mm^2. However 25mm diameter steel bar imported, recorded the highest yield and maximum tensile stress of 702.83 N/mm^2 and 790.43

N/mm^2 respectively as detailed in Table 4.Analysis of Fig. 5 and 6 revealed that rebars produced by Sentuo Steel Company obtained the longest total elongation even though they recorded the lowest maximum tensile stress values. The least total elongation of 10.52% was obtained by steel bar produced by Fabrimetal Limited.

4.1.1 Chemical composition of mild steel bars

The high strength values were due to very high carbon content of all the reinforcing steel bars in the country. The least carbon content of 1.165% in the mild steel category was recorded by United Steel Company which was high as compared to the required 0.24% by the BS 4449:2005+A2:2009 [1]. Ferro Fabrik Limited, Sentuo Steel Limited and Fabrimetal Limited recorded 1.541%, 3.183% and 2.544% respectively. Other alloying chemicals and impurities were equally relatively high compared to the BS449:2005 specification.

This high strength of high yield reinforcing steel bars from Fabrimetal Limited was obviously due to the high carbon content because the company recorded the highest carbon content of 9.348 % in the chemical analysis. Imported reinforcing bars recorded the lowest average carbon content of 1.845% while Ferro Fabrik and Sentuo Steel recorded 4.49% and 4.21% respectively as detailed in Table 2. None of the reinforcing bars traded in Ghana met the maximum carbon content requirement of 0.24%.

4.1.2 Ductility of reinforcement bars

Elongation at maximum force as a measure of ductility of the mild steel ribbed reinforcing bars traded in Ghana was averagely 17.41%. The elongation at maximum of the reinforcing bars ranges from 10.08% to 20.52%. These values met the GS 788-2:2018 minimum requirement of 2-8% of total elongation at maximum force.The mild steel bars had an average Tensile strength to yield strength ratio (R_m/R_{eH}) of 1.34 which is higher the $R_m/R_{eH} \leq 1.15$ required by GS788-2:2018 for a class B300A-B550C

The total elongation at maximum force ranges from 4.6% to 19.65% for high yield reinforcing bars traded in Ghana. Sentuo Steel Limited recorded both maximum and minimum total elongation at maximum force of 19.65% and 4.6% for the 16mm and 12mm nominal reinforcing bars respectively. The mean elongation at maximum force was 9.64% for the four companies as shown in Table 5. The four companies had total elongation at maximum force higher than the minimum range of 2.5% to 7.5% recommended by BS4449:2005+A2:2009 as shown in Table 5.

However, the 12mm nominal diameter high yield reinforcing bar from Sentuo Steel Limited and imported steel bar recorded 4.6% and 7.2% respectively of total elongation at maximum force which was within the minimum range 2.5 to 7.5% recommended by the BS4449:2005+A2:2009.

Generally, most of the steel bars exhibitedshiny surfaces with little or no cup-and-cone appearance at fracture dueto their high carbon content and associated brittleness. However, a few of them showed some necking and limited cup-and-cone surfaces at fracture. Fig.9: "a" and "b" show typical fracture surfaces of steel bars at failure.Table 5 show detailed tensile properties of reinforcing bars available in Ghana.

(a)Mild Steel Reinforcement Bar **(b) High Yield Reinforcement Bar**

Fig. 9: Typical Reinforcement Bars in Ghana at Failure

Table5Tensile Properties of reinforcement bars in Ghana

Bar Source	Bar Type	Nominal Bar Size (mm)	Bar Area (mm^2)	Yield Stress (R_{eH}) N/mm^2	Max Stress (R_m) N/mm^2	R_m/R_{eH}	Elongation at max force (%)	Classification with Table 4, BS 4449: 2005+A2:2009
FFL 12R	Mild Steel	12.00	113.10	464.20	545.19	1.17	14.16	B500C
USC 12R	Mild Steel	12.00	113.10	353.68	499.57	1.41	20.18	R_m/R_{eH} beyond limit
FAB 12R	Mild Steel	12.00	113.10	457.57	538.30	1.18	16.18	B500C
STS 12R	Mild Steel	12.00	113.10	362.52	499.57	1.38	20.40	R_m/R_{eH} beyond limit
FFL 16R	Mild Steel	16.00	201.06	487.41	527.20	1.08	10.08	B500B
USC 16R	Mild Steel	16.00	201.06	328.26	487.41	1.48	20.52	R_m/R_{eH} beyond limit
FAB 16R	Mild Steel	16.00	201.06	412.81	512.28	1.24	15.50	B500C
STS 16R	Mild Steel	16.00	201.06	343.18	522.23	1.52	19.80	R_m/R_{eH} beyond limit
USC 20R	Mild Steel	20.00	314.16	331.04	496.56	1.50	18.78	R_m/R_{eH} beyond limit
FAB 20R	Mild Steel	20.00	314.16	474.28	598.42	1.26	15.78	B500C
STS 20R	Mild Steel	20.00	314.16	331.04	493.38	1.49	20.17	R_m/R_{eH} beyond limit
FFL 12Y	High Yield	12.00	113.10	636.62	747.14	1.17	8.09	B500C
IMP 12Y	High Yield	12.00	113.10	674.20	760.41	1.13	7.20	B500B
FAB 12Y	High Yield	12.00	113.10	636.62	751.56	1.18	8.86	B500C
STS 12Y	High Yield	12.00	113.10	506.20	751.56	1.48	4.60	R_m/R_{eH} beyond limit
FFL 16Y	High Yield	16.00	201.06	576.94	616.72	1.07	8.65	B500A
IMP 16Y	High Yield	16.00	201.06	482.44	606.78	1.26	8.93	B500C

FAB 16Y	High Yield	16.00	201.06	696.30	815.67	1.17	7.59	B500C
STS 16Y	High Yield	16.00	201.06	341.93	497.36	1.45	19.65	R_m/R_{eH} beyond limit
FFL 20Y	High Yield	20.00	314.16	557.04	649.35	1.17	10.24	B500C
IMP 20Y	High Yield	20.00	314.16	588.87	741.98	1.26	8.25	B500C
FAB 20Y	High Yield	20.00	314.16	490.20	708.56	1.45	11.45	R_m/R_{eH} beyond limit
FFL 25Y	High Yield	25.00	490.88	570.41	723.20	1.27	12.65	B500C
IMP 25Y	High Yield	25.00	490.88	702.83	790.43	1.12	9.60	B500B

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5. Conclusion

None of the reinforcing steel bars available in Ghana market met BS4449+A2:2009 specification on chemical composition of steel for the reinforcement of concrete-weldable reinforcing steel-bar, coil and decoiled products. Even though carbon contributes to hardness, yield point and tensile strength steel bars, excess carbon reduces the weldability and ductility of the steel bars.It also make steel brittle. Steel milling companies in Ghana need to improve on the manufacturing process by introduction of oxygen into the molten steel during the manufacturing process to reduce excess carbon.

Mild reinforcing steel bars in Ghana had yield strength ranging from 328.26 N/mm^2 to 487.41 N/mm^2 and tensile strength from 487.41 N/mm^2 to 598.42 N/mm^2.

High yield reinforcing bars in Ghana had yield strength ranging from 341.93 N/mm^2 to 702.83N/mm^2 with mean value of 572.87 N/mm^2 and tensile strength ranging from 497.36 N/mm^2 to 815.67 N/mm^2 with mean value of 707.89 N/mm^2.

A totalof 64% of the rebarsmet the ductility requirement of $R_m/R_{eH}<1.35$ of the BS [6] specification for B500C. Howeverthe presence of high levels of carbon in the reinforcing bars made some of the rebars brittle. Most of the reinforcing bars achieved little or no necking at failure. There was little or no cup-and-cone shape at fracture of the some of the reinforcing bars at failure. However,the imported reinforcing steel bars showed relatively better necking at fracture than the local steel bars milled from scrapmetals.

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