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Research Article

Corrosion Behavior of Iron Steel Bars on the Ghanaian Market; Elemental Composition and Mechanical Properties Perspective

[1]J.B. Tandoh, [2]E.K. Amesimeku, [1]A. Forson, [1]C. Nuviadenu, [1]H. Ahiamadjie, [1]G. Quashigah, [1]E. Gazoya, [1]H. Sackey-Lee and [1]G.K. Banini
[1]Ghana Atomic Energy Commission (GAEC), P.O. Box LG 80, Legon, Accra-Ghana,
[2]Graduate School of Nuclear and Allied Sciences, University of Ghana P.O. Box AE1, Atomic-Kwabenya, Ghana

Abstract: This study seeks to determine the corrosion rates of three major iron rod brands on the Ghanaian market from Local and foreign origin, after exposure to 5% NaCl solution to simulate a salty environment. The impact salty environment has on the mechanical properties (Yield and Ultimate tensile strength) of the Iron rods was determined. After 60 days of exposure of iron rods to the simulated salty environment in the laboratory, appreciable loss in mass was observed, ranging from 14 to 25% for Local and foreign samples respectively. The mechanical properties (Yield and Ultimate tensile strength) of the iron rods were also negatively affected after the 60 days exposure to the salty environment, causing all samples to fail the minimum requirement set by Hellenic for Yield and Ultimate tensile strength.

Keywords: Accelerated corrosion, corrosion, iron rods, PIXE, proton induced X-ray emission, steel bars

INTRODUCTION

The construction industry over the past decades has been one of the fastest growing sectors of the Ghanaian economy (Osei, 2013). This rapid growth has created an avenue for some building contractors to root the selection of building materials such as steel bars, popularly called "Iron rods" which plays a vital role in the structural integrity of buildings just on the cost of the material but not on the quality. The main problem associated with Iron rods is corrosion (de Alcantara *et al*., 2015). Corrosion is the degradation of Iron when it comes into contact with the environment. There are several reported instances worldwide where the collapse of buildings has been attributed to the use of substandard materials, high chloride content in the cement which is believed contributes to the high corrosion rate of the iron steel bar reinforcement (Almarwae, 2017). In most developing countries the National Standards Authorities are the only accredited institute mandated to test the quality of iron rods. The authority performs mostly mechanical property tests such as yield strength, ductility, hardness and tensile strength without corrosion sensitivity test although from literature it has been argued that the elemental composition and corrosion resistance of iron steel rods have direct implication on their structural integrity with time (British Standard Institute (BSI), 2000). The high demand for Iron rods on the Ghanaian market has also made it lucrative for some manufacturing companies to produce and smuggle possible inferior, cheap Iron rods, which do not meet the correct standards onto the Ghanaian market. The authors believe the quality of an Iron rod should not only be dependent on its mechanical properties at the time of purchase but its sensitiveness to corrosion should also be a factor to be considered since corrosion degrades the structural integrity of the materials with time (El Maaddawy and Soudky, 2003). The objectives of this study are to determine the elemental signatures and corrosion rates for (3) major iron rods brands on the Ghanaian market using Proton Induced X-ray Emission (Ene *et al*., 2010) and also determine the mechanical properties (Ponle *et al*., 2014) (tensile strength, Yield and elongation) of these iron rods before and after various corrosion tests (International Stainless-Steel Forum, 2008).

MATERIALS AND METHODS

Sampling was carried out after a comprehensive market survey on the most purchased and used brands of iron rod on the Ghanaian market were performed. Three brands were purchased for this study; these were (1) from local origin and (2) from foreign origin. Since

Corresponding Author: J.B. Tandoh, Ghana Atomic Energy Commission (GAEC), P.O. Box LG 80, Legon, Accra-Ghana

Fig. 1: Picture of various Iron rods analyzed for this study

most iron rods are not labeled, the locally manufactured iron rod used in this study was purchased directly from the factory, whiles the imported brands from China and Ukraine origin were purchased from major retail outlets in Accra, Ghana. Samples were labeled Local1 for the sample manufactured locally, Foreign 1 (China) and Foreign 2 (Ukraine). Figure 1 indicates a picture of some of the samples used for this study.

Mechanical properties test: Two each of the samples were cut to a length of 450 mm and weighed. Its mechanical properties including its length and area were measured using the 300 kN hydraulic Universal Testing Machine (ASTM A370-14, 2014). The measurement was based on a principle where a force is applied to the sample until it breaks into two, in the process ultimate tensile strength, yield and elongation were determined.

Corrosion test and corrosion rate: Four samples from each brand were placed in a 5% NaCl solution to induce a corrosive environment. A typical bath contained a single brand of iron rod. After a 21 day period of exposure of samples to NaCl bath solution, (2) were taken out, cleaned and dried, weighed and mechanical properties tested. This process was repeated for the other two samples left in the bath after a 60 day period. Corrosion rates were determined from mass loss of the samples after stimulated corrosion test periods in the 5% NaCl bath as indicated in Eq. (1) (Dean Jr, 1997):

$$C_R = \frac{k \times \Delta w}{A \times T \times \rho} \tag{1}$$

where,

C_R = Corrosion rate
Δw = Weight loss in gram
A = Exposed surface area of Iron rod
ρ = Density of iron rod
T = Time of exposure in hours
k = Constant for unit conversion.

Elemental analysis using PIXE: Portions of each 16 mm diameter iron steel bars of Local 1, Foreign 1 and Foreign 2, were cut and well prepared for Particle Induced X-rays Emission (PIXE) analysis to determine the elemental composition, of locally manufactured and imported iron steel bars on the Ghanaian market using a 1.7 MV Pelletron accelerator. Spectra acquisition and analysis were done with commercial GUPIX software (Maxwell *et al*., 1995). The Experimental Setup parameters for PIXE analysis for this study are summarized below:

- Type of Incident Ion: H+
- Incident Ion Energy: 2.3 MeV
- Incident Ion normal with sample: 90°
- Silicon Drift Detector angle to target sample: 45°
- Incident Ion beam current: 20 uA
- Total Beam Charge collected: 10 uC

RESULTS AND DISCUSSION

The elemental signatures of all samples were determined prior to the mechanical properties test of which ultimate tensile strength; yield strength, maximum elongation and mass loss in steel samples were determined.

Elemental composition analysis: Although it is evident that some alloying elements enhance the mechanical properties of iron rods, it is also evident that some elements also act as catalysts to increase corrosion (Salman and Djavanroodi, 2018). Figure 2 presents a fitted spectrum of the Local Iron rod sample analyzed. A total of (11) elements could be identified. All peaks were fitted with the GUPIX software with fit residuals <15%.

From Fig. 2 to 4, Iron (Fe), which is the main element in iron rods, was prominent in all samples analyzed. The presence of manganese, Mn, in steel bars, from literature has been found to increase the

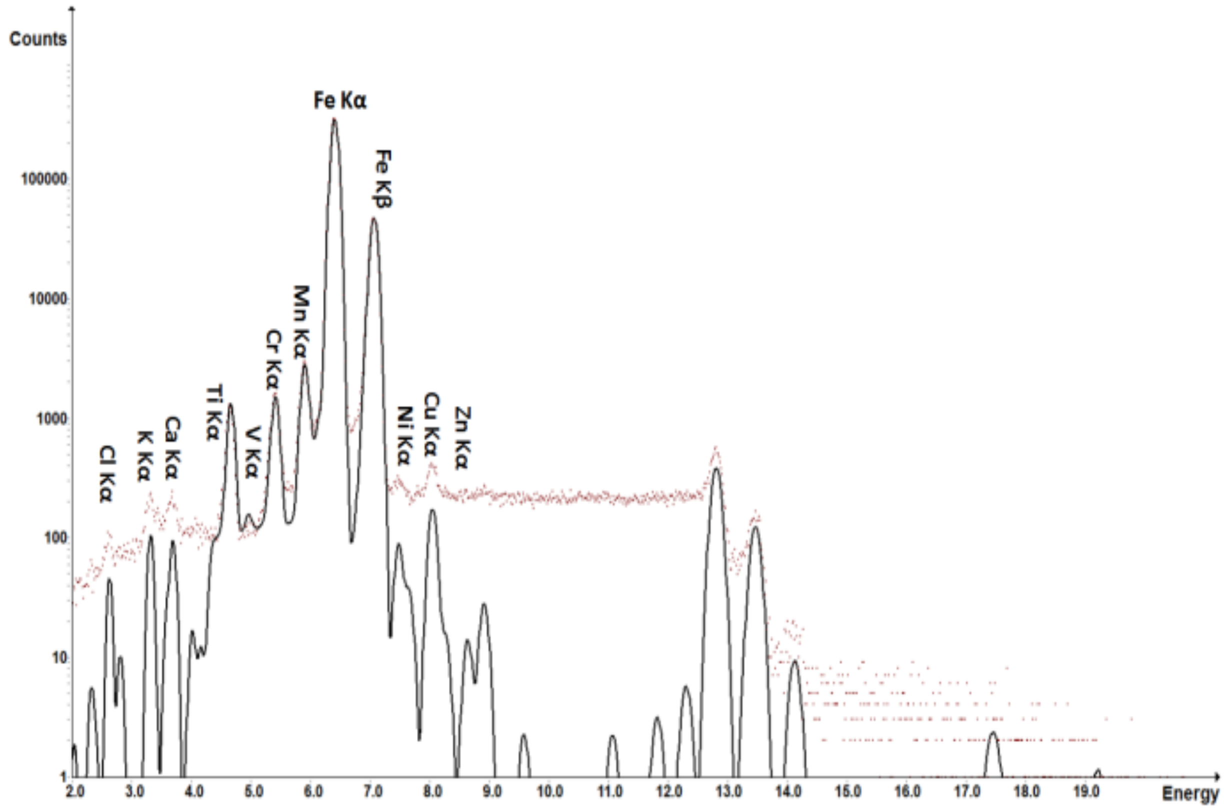

Fig. 2: Fitted PIXE spectrum of local iron rod

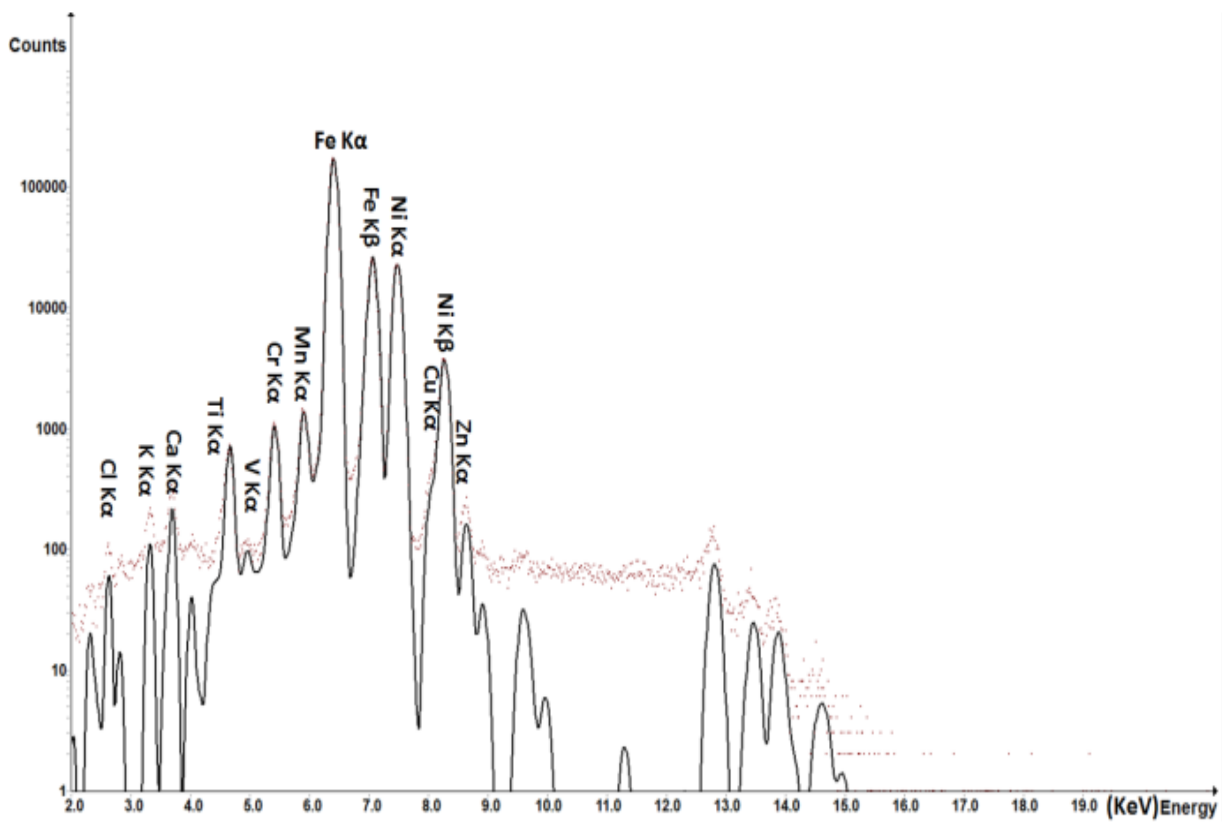

Fig. 3: Fitted PIXE spectrum of Foreign 1 (China) Iron rod

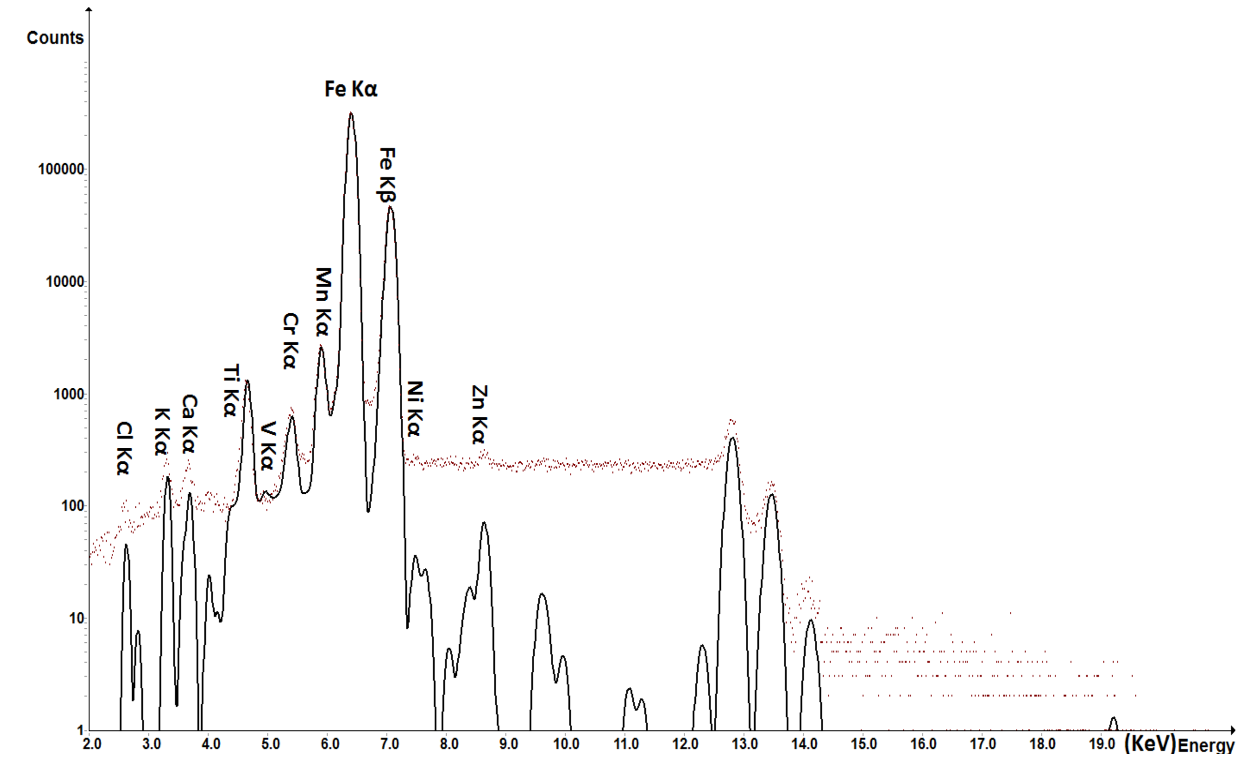

Fig. 4: Fitted PIXE spectrum of Foreign 2 (Ukraine) Iron rod

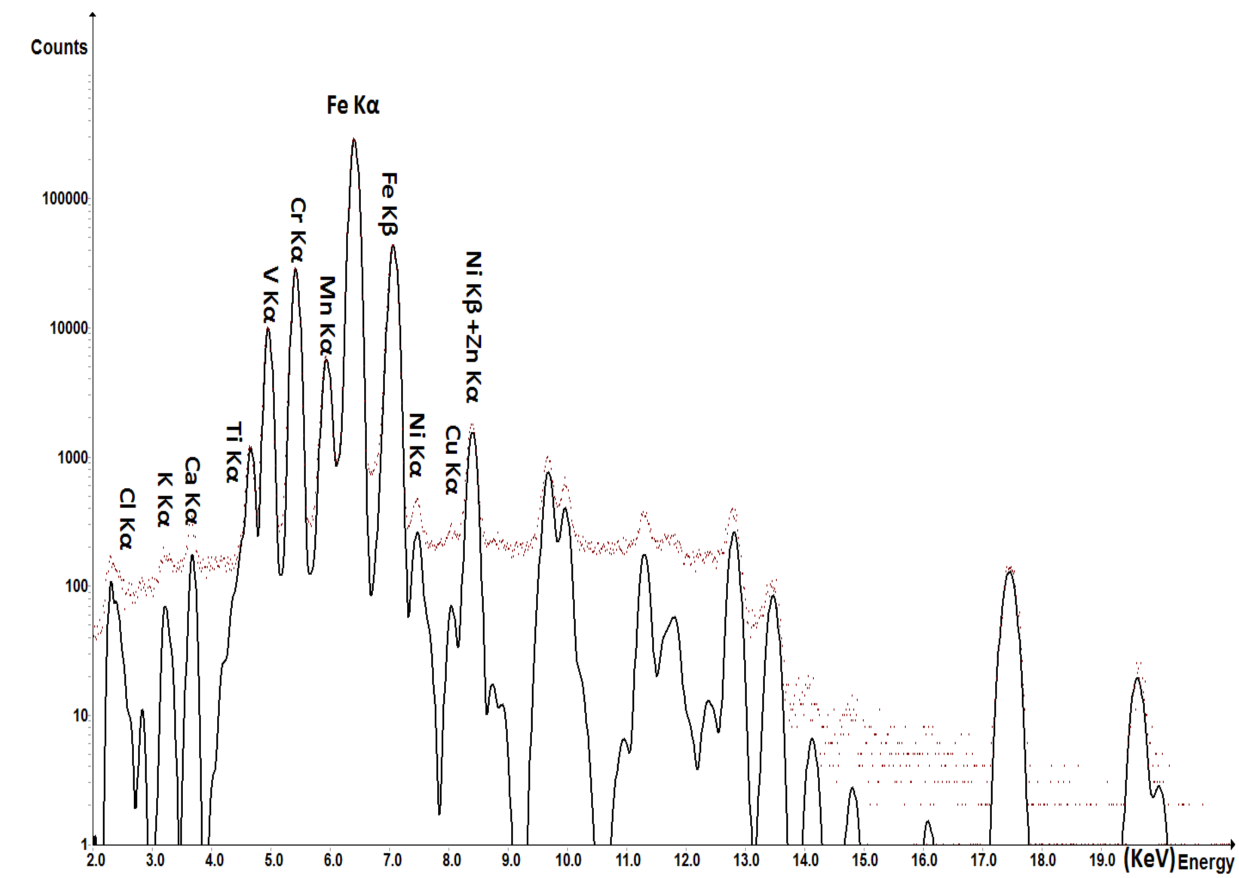

Fig. 5: Fitted PIXE spectrum of NIST SRM 1157 tool steel

Table 1: Elemental composition of all samples analyzed in this study

Elements	Foreign1 (China) wt. (%)	Foreign2 (Ukraine) wt. (%)	Local (Ghana) wt. (%)
Cl	0.16	0.09	0.09
K	0.07	0.08	0.05
Ca	0.09	0.04	0.03
V	0.01	0.00	0.01
Cr	0.24	0.08	0.23
Mn	0.36	0.59	0.59
Fe	60.37	98.69	93.07
Co	0.40	0.22	0.26
Ni	27.24	0.05	0.12
Cu	0.39	Nd	0.26
Zn	0.33	0.14	0.02

Table 2: Validation of analytical technique using standard reference material

Elements	Measured	NIST SRM 1157	Deviation (%)
V	1.79	1.820	1.65
Cr	4.43	4.360	1.61
Mn	0.39	0.340	14.71
Fe	87	81	7.52
Ni	0.26	0.228	14.04
Cu	0.09	0.088	2.27
Mo	5.56	4.860	14.40
W	7.58	7.560	0.26

hardenability of steel and also act as a deoxidizer in steel. Mn was present in all samples studied. Other element like Chromium (Cr) which from literature has been found to enhance corrosion resistance in steel, were identified in all the samples. Figure 5 shows the spectrum of the NIST metal standard irradiated for quantitative analysis in this study.

From Table 1, the composition of Iron (Fe) in the Foreign1 sample initially raised a bit of concern as its value was far less than all the other rods analyzed, thus 60%. Iron as mentioned earlier is the key element in iron rods. Manganese in all samples analyzed was less than 1%, with Foreign 1 sample again recording the lowest value of 0.36%. Comparable levels of chromium were measured for Foreign1 and Local1 samples, with Foreign 2 recording the lowest. Chromium as indicated earlier enhances corrosion resistance in iron rods, therefore raising concerns of the low value recorded for the foreign 2 sample (0.08%). Nickel, has been found not to directly increase resistance of Iron rods to corrosion initiation, but it effectively slows down the corrosion process once it has started. Nickel was present in all samples measured for all samples, but surprisingly, its content in the Foreign1 sample was very high (27%).

Table 2, shows the concentrations obtained for the NIST SRM 1157, a steel standard, using the current procedure for PIXE at our facility compared to the certified values for the NIST SRM 1157 standard. From the table, the deviations from the standard value for all elements were below 15%.

Mechanical properties of Iron rods: Figure 6, shows the Yield Strength recorded for all samples. The blue, red and green lines indicate the Yield Strength recorded for Local 1, Foreign 1 and Foreign 2 samples respectively before and after corrosion tests over the 21- and 60-days period. Measured values were compared to the Hellenic international standard (Government Gazette Issue, 2000) (min.~500 N/mm^2) and the Ghanaian standard (GS 788-2:2008) for Yield strength (min.~300 N/mm^2). Before samples were subjected to corrosion test, the yield strength measured for all samples were above the Ghana Standard Authority value of 300 N/mm^2. As Yield strength is the amount of Stress that the material can take before it starts to deform, one can clearly conclude that the Foreign2 sample can withstand more stress than all the other samples, with the local sample recording the lowest. These results also indicated that the quality of the Iron rods on the market meets the Ghanaian requirement for quality assessment purposes. After 21 days of exposure of samples to 5% NaCl solution, there was a reduction in the yield strength of all samples

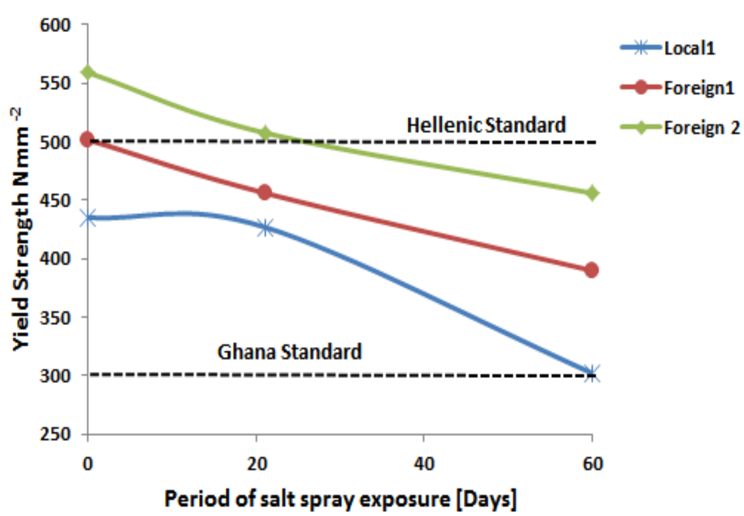

Fig. 6: Graph of yield strength for samples before and after corrosion test

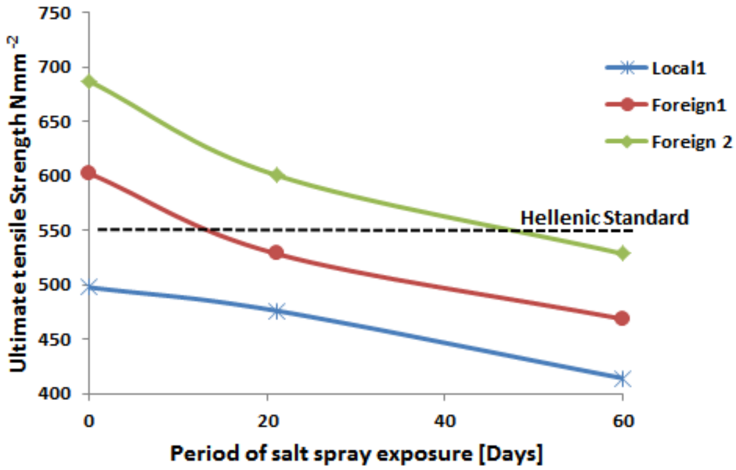

Fig. 7: Graph of ultimate tensile strength for all samples before and after corrosion test

although values were still above the standard requirement. After 61 days of exposure to 5% NaCl solution, there was a significant reduction in the Yield strength of the Local 1 sample from 435 to 302 N/mm^2; this value is just on the border line of the Ghana Standard authority value of (300 N/mm^2). The outcome was different for the other two samples (Foreign 1 and Foreign 2) which were far above the minimum standard requirement for the Yield strength of iron rods. This indicates that the foriegn2 and foreign 1 sample are relatively more resistant to corrosion, meaning corrosive environment is likely not to cause much degradation to its structural integrity. It is also evident from this outcome that 61 days of exposure of Local 1 sample to 5% NaCl solution degrades the Yield strength properties of the sample such that it almost fails to meet the National Standard requirement set for Iron rods. Although, in Ghana, the Hellenic standard is not applicable to our standard procedure for measuring the mechanical properties of steel bars, the authors decided on a hunchback to compare the yield values to the Hellenic standard for comparison purposes only. The Hellenic standard is the internationally accepted standard for re-enforced steel. Local 1 sample clearly was below the standard value, even before any corrosion tests were carried out. Foreing1 sample was just above the limit. The only sample which was clearly above the Hellenic standard limit for Yield was Foreign2 sample. All samples including Foreign 2 failed to meet the requirement after 60 days of exposure to the 5%NaCl.

Similar trend was observed for the Ultimate strength test which indicates the maximum stress the material can take before it breaks as shown in Fig. 7. Foreign 2 still recorded the highest followed by Foreign1 and finally Local 1. It is also evident that after 60 days of corrosion, the Ultimate strength of all samples declined significantly below the Hellenic standard value.

The elongation of iron materials is proportional to their ductility, which is defined as the ability of a material to with stand changes in length when subjected to tensile forces. The elongation of iron materials is proportional to their ductility, which is defined as the ability of a material to withstand changes in length when subjected to tensile forces. The percentage elongation is the amount of strain that the iron steel bar can experience before rapture in the tensile testing. The larger the elongation value of the iron steel bar, the better the ductility of the iron steel bar. From Fig. 8, the percentage elongation of the Local 1 sample increased with corrosion exposure time. The high percentage elongation range of Local 1 iron steel bar enabled it to neck for long time after it exceeded its ultimate tensile strength before fracture. Also, from Fig. 3, it was observed that the Foreign 1 percentage elongation rather declined from 26.25 to 22.50 %, this was due to the less percentage content of iron in Foreign1 as can be seen in Table 1.

Corrosion rate: Corrosion rates were computed from measured parameters such as weight loss, exposed surface area, density of iron rods and time of exposure to NaCl solution. The average mass loss is presented in Fig. 9 and 10.

From Fig. 9, it is evident that all samples recorded a decline in mass after exposure to 5% NaCl solution. The average weight losses of all samples were higher during the first 21 days of exposure to the 5% NaCl solution, but subsequently reduced. After 60 days of samples exposure to NaCl solution, the mass loss of the corroded specimen is about 14% for the Local 1 sample, which translates into a mass loss of 91 g of the mass of the original specimen (before corrosion) as indicated in Fig. 10. Mass loss for the foreign 1 and foreign 2 samples were 220 and 204 g respectively which translates into 28 and 25%, respectively. Although the spray test undertaken for this

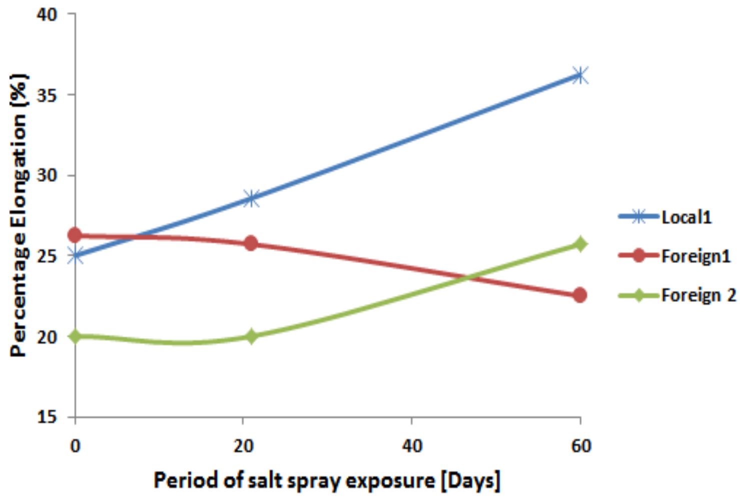

Fig. 8: Plot of the percentage elongation of all samples before and after corrosion test

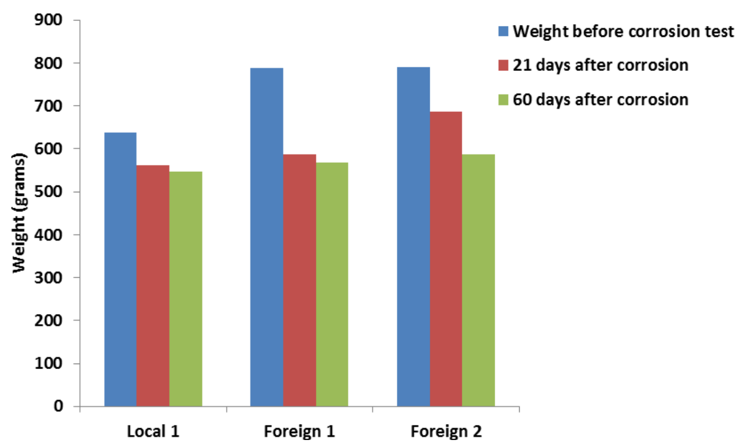

Fig. 9: Plot of weight of iron rods as a function of exposure time to 5% NaCl solution

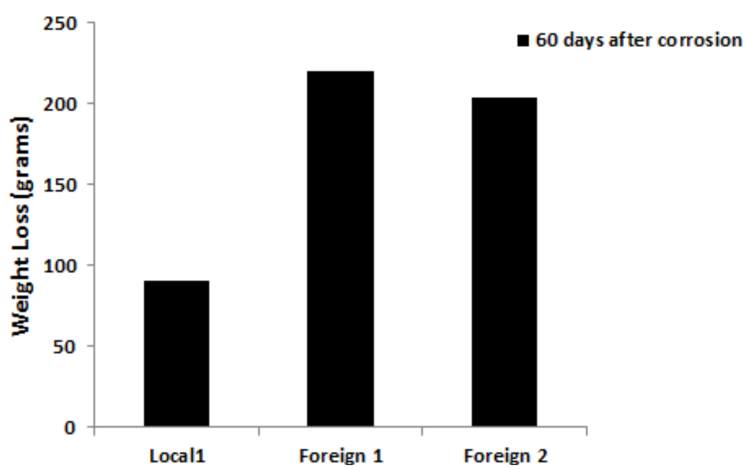

Fig. 10: Plot of weight of iron rods as a function of exposure time to 5% NaCl solution

study is an accelerated corrosion test, it gives an insight into the sensitivity of the material to corrosion.

It is evident from Fig. 11, that there was intense corrosion within the first 21 days of sample exposure to NaCl solution. The rate of corrosion determined for the Foreign 1 sample was very high, which means it is very sensitive to corrosion. Surprisingly, after the 60 days of exposure, the rate of corrosion for all samples

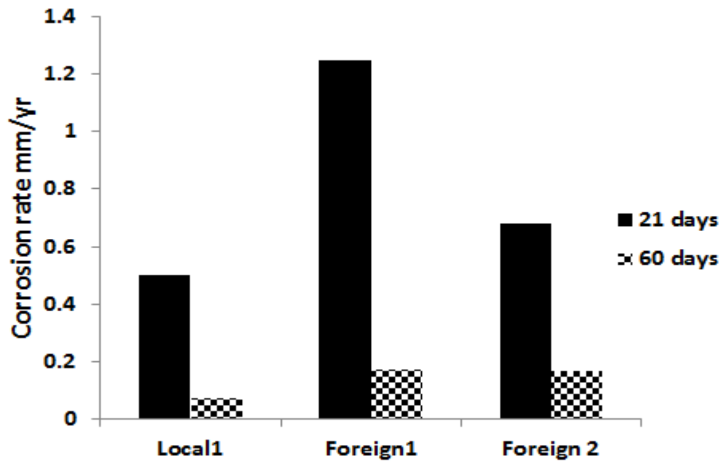

Fig. 11: Plot of the corrosion rate of Iron rods with exposure time to NaCl solution

drastically reduced, recording rates of 0.07, 0.17 and 0.16 mm/year for Local 1, Foreign 1 and Foreign 2 samples respectively. The drastic reduction of the rate of corrosion when exposed for the 60 day period can be due to the formation of an oxide layer on the surface of the rod which acts as a protective layer to prevent further corrosion. The local sample recorded the lowest weight loss amongst the other two brands.

CONCLUSION

- Three major brands of Iron rods on the Ghanaian market from Local and Foreign Origin have been analyzed for mechanical property test, corrosion sensitivity test and elemental composition analysis.
- Per the minimum standard requirement set by the Ghana Standards Authority for Yield strength (i.e., 350 N/mm^2), all Iron rods analyzed before corrosion test were above this value.
- Per the Hellenic Standard which requires a minimum Yield strength value of 500 N/mm^2, only the foreign 2 sample with origin from Ukraine was clearly above this value.
- After 60 days of exposure of all samples to 5% NaCl solution which simulates a salty environment, all samples recorded appreciable loss in mass ranging from 14 to 28% of original mass.
- The effect of exposing iron rods to 5% NaCl for 60 days have drastic negative effect on the Yield and Ultimate tensile strength values as per the Hellenic standard. All samples failed the minimum requirement set by the Hellenic for Yield and Ultimate tensile strength.
- Per the corrosion rates estimated for all samples, after 60 days of exposure to 5% NaCl solution, Local 1 sample recorded the lowest value of 0.07 mm/year whiles foreign 1 recorded the highest (0.17 mm/year). This means that the Local 1 sample is more resistant to corrosion compared to the rest of the samples.
- Since corrosion plays a critical role in the degradation of the mechanical and structural integrity of Iron rods with time, Corrosion tests should be incorporated in the routine tests for the quality assessment of Iron steel bars for construction works.

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CONFLICT OF INTEREST

This study was fully self-sponsored and its findings were not influenced by anybody.

REFERENCES

Almarwae, M., 2017. Structural failure of buildings: Issues and challenges. World Scientific News, 66: 97-108.

ASTM A370-14, 2014. Standard Test Methods and Definitions for Mechanical Testing of Steel Products, ASTM International, West Conshohocken, PA. Retrieved from: www.astm.org.

British Standard Institute (BSI), 2000. Testing Hardened Concrete. Tensile Splitting Strength of Test Specimens. BS EN 12390-6.

Dean Jr, S.W., 1997. Electrochemical Methods of Corrosion Testing. In: Baboian, R. (Ed.), Electrochemical Techniques for Corrosion, National Association of Corrosion Engineers, Houston, TX, pp: 52-53.

De Alcantara, N.P., F.M. da Silva, M.T. Guimarães and M.D. Pereira, 2015. Corrosion assessment of steel bars used in reinforced concrete structures by means of eddy current testing. Sensors (Basel), 16(1).

El Maaddawy, T.A. and K.A. Soudky, 2003. Effectiveness of impressed current technique to simulate corrosion of steel reinforcement in concrete. J. Mater. Civil Eng., 15: 41-47.

Ene, A., I.V. Popescu, C. Stihi, A. Gheboianu, A. Pantelică and C. Petre, 2010. PIXE analysis of multielement samples. Romanian J. Phys., 55(7-8): 806-814.

Government Gazette Issue, 2000. Hellenic Regulation for the Technology of Steel in Reinforced Concrete. No. D14/36010-29.2/24.3.

International Stainless-Steel Forum, 2008. The Salt Spray Test and its Use in Ranking Stainless Steels. The Test and its Limits. International Chromium Development Association (ICDA). Retrieved from: www.Worldstainless.org.

Maxwell, J.A., W.J. Teesdale and J.L. Campbell, 1995. The Guelph PIXE software package II. Nucl. Instrum. Meth. B, 95(3): 407-421.

Osei, V., 2013. The construction industry and its linkages to the Ghanaian economy-polices to improve the sector's performance. Int. J. Develop. Econ. Sustain., 1(1): 56-72.

Ponle, E.A., O.B. Olatunde and O.W. Awotunde, 2014. Mechanical properties of reinforcing steel rods produced from recycled scraps. Int. J. Eng. Sci., 3(2): 14-34.

Salman, A. and F. Djavanroodi, 2018. Variability of chemical analysis of reinforcing bar produced in Saudi Arabia. Proceeding of the International Conference on Materials Engineering and Applications IOP Conference Series: Materials Science and Engineering, Vol. 348.