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Chemical Composition of Commonly Used Local and Foreign Steel Reinforcements and the Effects on the Strength Property of the Material Composites

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ABSTRACT

In recent times, structural failure of buildings and civil infrastructures are on the increase in developing countries. These failures can be attributed to the use of; poor material, influx of quacks, unethical professional practices, poor construction methodology and the use of unverified newly introduced reinforcements. This study investigated the chemical contents of commonly used new local steel reinforcements and imported steel reinforcements as to the level of compliance with ASTM A 706 and BS 4449 specifications. The effects of the percentage composition on the strength properties of the material and consequential effects on concrete composite were discussed. Chemical analyses of local bars revealed higher sulphur and phosphorus contents which increased brittleness though with enhanced strength. The higher contents of minor elements like silicon, Manganese, Chromium, Zinc in local steel specimens increased loss of mass in aqueous solutions and in water compared with the foreign specimens. In conclusion, while the imported bars satisfied the ASTM and BS standards in terms of the percentage composition of the elements, local bars did not meet these standards. Hence, it is recommended that the development of National Building Codes that reflect the actual material characteristics to avert premature failure for concrete structures reinforced with the local bars.

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1. Introduction

The recurrent premature failures of public infrastructure which render most constructed facilities structurally deficient and functionally obsolete require urgent attention. Statistics have shown that a significant number of structural failures can be attributed to poor material quality, influx of quacks and unethical professional practices, poor construction methodology, workmanship and unverified newly introduced reinforcements [1–4]. The two main materials used for constructional purposes in reinforced concrete structures are concrete and steel reinforcements [5]. The Achievement of an acceptable probability that any designed structure would perform satisfactorily during their intended life (BS 8110) [6] is often hampered by noncompliance with structural design specifications and non-conformance of structural properties of materials used in the actual construction to the properties of materials specified at designed stage [2]. In recent times, structural failure of buildings and civil infrastructures are on the increase in developing countries, Nigeria a case study [1,4].

In developing countries like Nigeria and most African countries where imported steel manufactured to world best standards is very expensive, local milling companies and private individuals have taken up the challenge to re-cycle obsolete vehicle metal parts, machine metal parts and household metal waste for the production of structural steels and reinforcing steels [7]. The registered indigenous steel reinforcements 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 [7]. In fact, preliminary investigations revealed that there are so many of such local steel companies operating in Nigeria [8,9]. The steel reinforcing bars required for structural concrete is partly produced locally by the country's inland rolling mills while the balance is sourced through importations of others produced outside the country . However, the few steel companies that are operational, though with low capacities, is now dependent on recycling of scrap iron and steel obtained mostly as solid wastes. (Ohimain, 2013; Ohimain and Jenakumo, 2013.Establishments in this industry produce steel by melting iron ore, scrap metal, and other additives in furnaces [10]. Structural steel products are manufactured to conform to the specification given in BS 5950 [11]. The previously used standard code for wieldable structural steels, BS 4360 [12] has been replaced by a series of Enronorm specifications for technical delivery requirements, dimensions and tolerance. Steel is composes of about 98 percent of iron with the main alloying elements carbon, silicon and manganese. Copper and chromium are added to produce the weather-resistant steels that do not required corrosion protection [13]. Structural steel is basically produced in three strength grades, viz: S 275, S 375 and S 460 [9]. The design properties; strength, ductility, impact resistance and wieldability depends on the chemical composition of the steel bar [14,15],. However these properties are often affected with deterioration overtime due to corrosion of the steel reinforcements. Lim. S. et al: (2016) reported that the severity of damage due to corrosion on reinforced concrete (R.C) composites primarily depended on the magnitude and location of the steel corrosion and also from the experimental steel weight loss data was used for modeling carried out, it was reported that there is residual reduced steel cross-section, reduced concrete strength and deteriorated bond interface. It was reported that corrosion of steel is an electrochemical process causes the degradation of material and when the steel structures exposed to the extreme atmosphere, especially marine and highly polluted industrial environment are subjected to corrosion. Corrosion damages the superficial layer of steel rebar thereby adversely affect the mechanical properties in terms of strength and ductility [16]. The corrosion caused by penetration of chloride on reinforcing steel rebar embedded in concrete appears to affect in a significant way the behavior of rebar. Park *et al.* [17] discovered that sulphate is soil and ground water may cause damage to the concrete in underground structures. Chloride ion roles in iron's corrosion was assessed from the viewpoint of developing the concept that would lead to a general explanation that experimental observations relating to such factors as the oxygen affect, concentration, cation, temperature, and pH dependence are reviewed [18]. Corrosion is the chemical attack or electrochemical reaction between a material, usually metal, and its environment that produces a deterioration of material and it properties. ASTM standard [19]. There is Corrosion inhibitors (CIs), which are substances input into an aggressive environment to reduce the corrosion rate of a metallic material by inducing a change at the solid/liquid interface, Nautiyal et. al*.,* [20]. This method of corrosion check is commonly used in manufacturing and steel production industries, and is also developed for a variety of applications.

2. Methodology

This study opted for the most commonly used steel reinforcement types for civil and building construction works for a realistic judgment. The chemical analysis of the most commonly used imported and local steel reinforcing steel bar samples was carried out at the Metallurgical Laboratory of University of Lagos, Lagos, Nigeria. The average values of the results obtained from a specimen of five samples were analyzed for twenty-six (26) chemical constituents using Optical Emission Spectrometry method and five of these constituent values were compared with ASTM [19], BS 4449 [21] and Nigerian Standard NST65 [22] to ascertained the level of compliance with the standards. The steel reinforcements were obtained from imported and local sources. This is imperative for comparative investigation and analysis. Most steel reinforcements imported into Nigeria are majorly from Ukraine. The locally produced steel reinforcements were obtained from six local companies mostly based in Lagos State. They predominantly use scraps as their major raw materials for producing steel. These industries are: Major, Federated, Sun Hassan, LCI, Pulkit, and Top. Determination of the mass loss when fully immersed in distilled water, and 5% solution of H_2SO_4, HCl, NaOH, Na_2SO_4 in soluble water over a total period of six weeks were carried out on foreign and local steel reinforcements.

3. Result and discussions

3.1. Chemical composition

The results obtained from a specimen of five samples were analyzed for twenty-six (26) chemical constituents using Optical Emission Spectrometry method and five of these constituent values were compared with ASTM [19], BS 4449 [21] and Nigerian Standard [22] as presented in Table 1.The steel bars experimented were obtained from imported and local sources. Most steel rebars imported into Nigeria are majorly from Ukraine. The locally produced rebars were obtained from six sources mostly based in Lagos State. These industries are Major, Federated, Sun Hassan, LCI, Pulkit, and Top. Typical chemical ingredients that have essential controlling influence on the properties of steel rebars are presented in Table 1 and plotted in Figures 1 to 7 for easy comparison with applicable standards. Though lower carbon content reduces the strength of steel, while the higher value makes steel brittle and unwieldable [16]. The imported steel samples from Ukraine produce carbon contents 0.202% fall within the NST-65-Mn, ASTM A706 and BS 4449 and specifications of 0.35%, 0.3% and 0.25% maximum values respectively.

Among the locally produced steel bars, carbon contents of specimens from Sun Hassan and Top steel (0.239 – 0.249%) satisfied BS 4449 [21], while all except Federated and Pulkit met the ASTM requirement for carbon content (Figure 1). Carbon is the cheapest and the most effective alloying element for hardening iron. Higher carbon contributes to the tensile strength of steel for higher load bearing capacity. Much lower carbon content of less than 0.1% will reduce strength, while higher carbon content of 0.3% and above makes the steel bars unweldable and brittle [23] . It is therefore evident that the strength of Federated and Pulkit steel specimens were enhanced at the expense of weldability and ductility. The requirements for silicon were satisfied by the NST-65-Mn and ASTM A706 with limiting values of 0.3% and 0.5% respectively (see Figure 2). All the steel rebars, local or imported, produced from the investigated sources are within the specifications. Manganese maximum content in steel of 1.5% and 1.6% are specified by ASTM A706 and NST-65-Mn respectively. All the steel specimens were much lower than the maximum specified values, Figure 3. It was reported that higher manganese content in steel increases the tensile strength and also the carbon equivalent property [24]. It can be inferred that the tensile strengths of these specimens are more likely not to be extremely enhanced.

On the other hand, phosphorous content is often present as an impurity which increases strength and brittleness. Higher phosphorous content contributes to the increase in strength and corrosion resistance properties, but brings brittleness due to formation of low euctoidphosphicles in the grain boundary [13,24]. The maximum limits mostly recommended by major international standards are in the range 0.04 – 0.06%. It is obvious from Table 1 as well as Figure 4 that all the specimens were at the upper limits – implying the presence of impurities. However, the Ukraine imported type had extremely high phosphorous content indicating much higher impurities than other samples. Similar to phosphorous, sulphur presence indicates the presence of impurity in steel which increases impurity. The presence of higher sulphur content makes the bar brittle during twisting, as higher sulphur content brings the hot shot problems during rolling [23]. Presence of sulphur is limited to a maximum value of 0.045%, 0.050% and 0.040% for ASTM A706, BS 4449 and NST-65-Mn respectively. It is evident from Figure 5 that the entire steel bar specimens investigated except those from Pulkit and Ukraine exceeded all the required limits. In fact, Pulkit and Ukraine did not meet NST-65Mn limit, but were within the other specified limits. Figure 6 showed the graphical comparison of the chromium contents of the local and foreign steel rebars. Although no specific limiting values were found for chromium content in steel rebars, extensive literatures have shown that the presence of the element influences the weldability and corrosion resistance of steel bars [15,23,24],. Oftentimes, chromium is present as an impurity from the scraps and influences carbon equivalent [21]. Copper is a pearlite stabilizer that increases the strength and corrosion resistance property of the reinforcing bars [18]. NST-

65-Mn limits copper content in steel rebars to 0.025%, while no specific limit was found for other international standards. Figure 7 clearly shows that all the steel samples investigated far exceeded the 0.025% limit.

3.2. Percentage mass loss in water and in aqueous solution

The pattern of the percentage loss in weight for both local and foreign reinforcements over a period of six weeks is presented in Figures 11. It could be seen from the figures that the percentage mass loss of local and foreign showed an increase linear deterioration pattern with percentage mass loss in local bars about 80% higher than the imported bars. The widest margin was observed at the end of the 4th week when the local bars lost 143% mass higher than the imported bars. This could be explained on the points that the preservative elements such as Silicon, Chromium, Manganese, molybdenum and tin are higher in local steel compared with the foreign steel (see Figures 2, 6, 9 -10), However, the margin closed up to about 9% at the end of the 6th week. The tests were carried out only for six weeks, it is recommended that the test be extended for a period of one or two years to see if equilibrium state could be reached where no more mass lose irrespective of the age will be obtained.

Table 1
Chemical analysis of steel reinforcing bar samples.

International standards: ASTM A706/ A706M (2013) and BS 4449 (2001)

Chemical Content (%)	**Prominent Steel Reinforcing Bars Sources in Nigeria**							**International Standards**		
	Major	Federated	Sun Hassan	LCI	Pulkit	Ukraine	Top	ASTM A706	BS 4449	Nst-65 -Mn
C	0.284	**0.318**	0.249	0.258	0.367	0.202	0.239	0.30	0.25	0.35
Si	0.17	0.246	0.255	0.271	0.294	0.18	0.25	0.50		0.30
Mn	0.485	0.88	0.85	0.86	0.75	0.7	0.811	1.50		1.60
P	**0.058**	**0.052**	**0.05**	**0.042**	**0.06**	**0.5**	**0.06**	0.06	0.05	0.04
S	**0.054**	**0.052**	**0.054**	**0.052**	0.041	0.041	**0.053**	0.045	0.05	0.05
Cr	0.206	0.181	0.192	0.193	0.151	0.203	0.194			
Ni	0.099	0.114	0.127	0.127	0.076	0.108	0.115			
Mo	0.014	0.022	0.036	0.032	0.015	0.011	0.027			
Al	<0.0001	0.0005	<0.0001	<0.0001	0.0012	<0.0001	<0.001			
Cu	0.209	0.215	0.209	0.209	0.201	0.398	0.226			0.025
Co	0.0062	0.012	0.009	0.0093	0.0064	0.0089	0.01			
Ti	0.0007	0.0008	0.0006	0.0005	0.0008	0.0009	0.0009			
Nb	0.0073	0.0077	0.0081	0.0074	0.0086	0.0074	0.0091			
V	0.0041	0.0023	0.0017	0.0019	0.0051	0.0012	0.0015			
W	<0.0001	0.0014	<0.0001	<0.0001	0.013	<0.0001	0.0017			
Pb	<0.0001	<0.0001	<0.0001	<0.0001	0.004	<0.0001	<0.0001			
B	0.0053	0.0021	0.0011	0.0017	0.0024	0.0013	0.0015			
Sn	0.019	0.012	0.012	0.013	0.0097	0.012	0.0133			
Zn	0.002	0.0044	0.0034	0.0032	0.0039	0.0032	0.005			
As	<0.0001	<0.0001	<0.0001	<0.0001	0.001	0.001	<0.0001			
Bi	0.001	0.0009	0.0011	0.001	0.0009	0.0009	0.0013			
Ca	0.0012	0.0013	0.0008	0.001	0.0015	0.0007	0.0012			
Ce	0.0025	0.0034	0.0035	0.0027	0.0033	0.0032	0.0037			
Zr	0.001	0.0016	0.0012	0.0018	0.0018	0.0014	0.0018			
La	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	0.002	<0.001			
Fe	98.4	97.9	97.9	97.9	98.0	98.1	97.8			

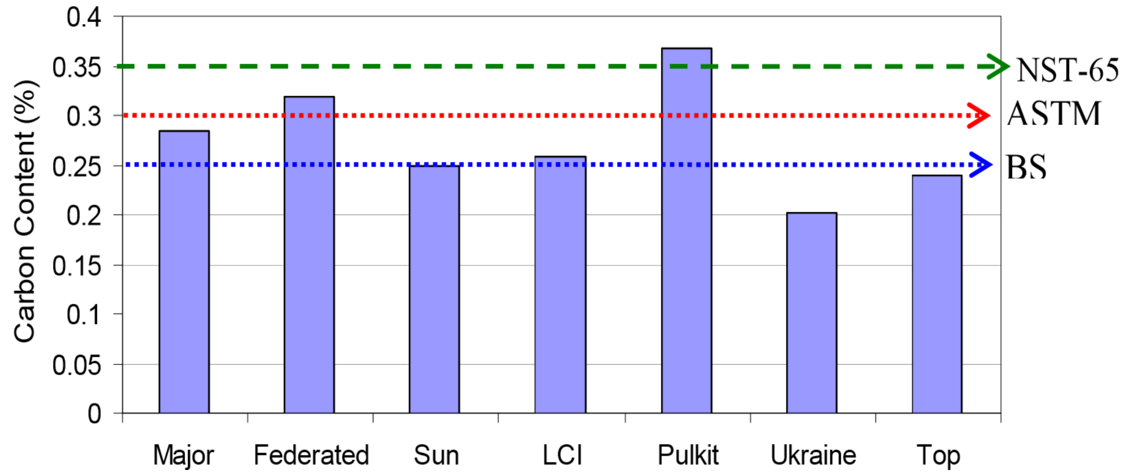

Fig. 1. Carbon(C) contents in steel specimens.

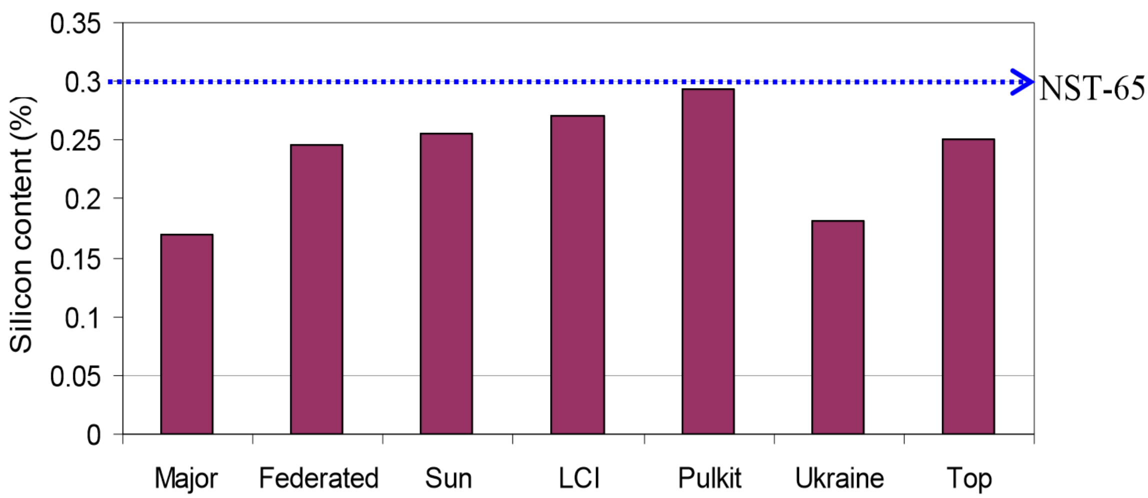

Fig. 2. Silicon(Si) contents in steel specimens.

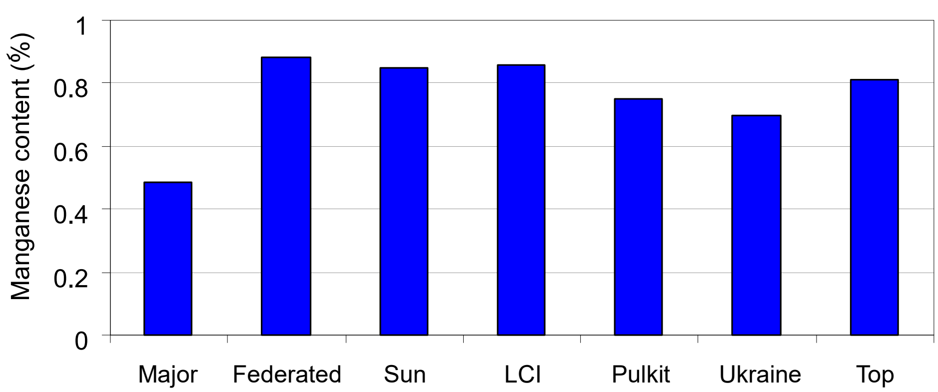

Fig. 3. Manganese(Mn) contents in steel specimens.

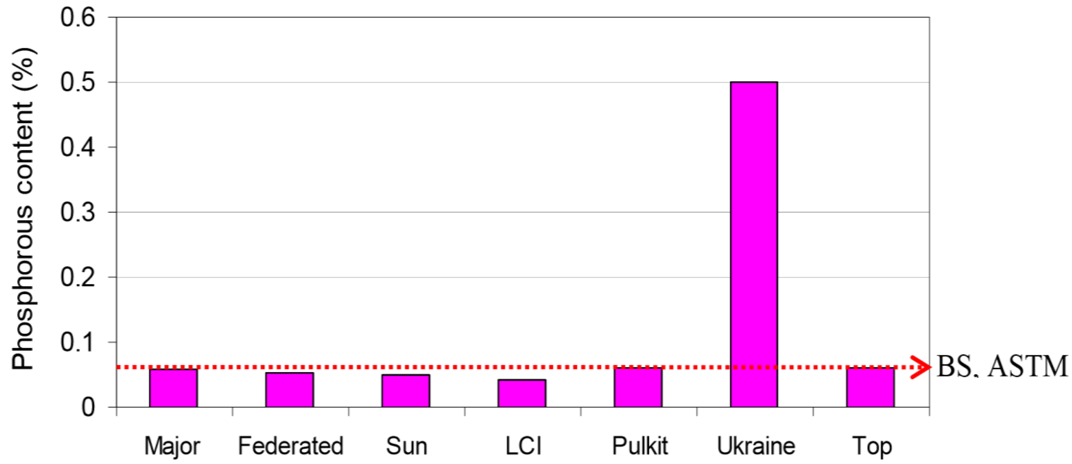

Fig. 4. Phosphorous (P) contents in steel specimens.

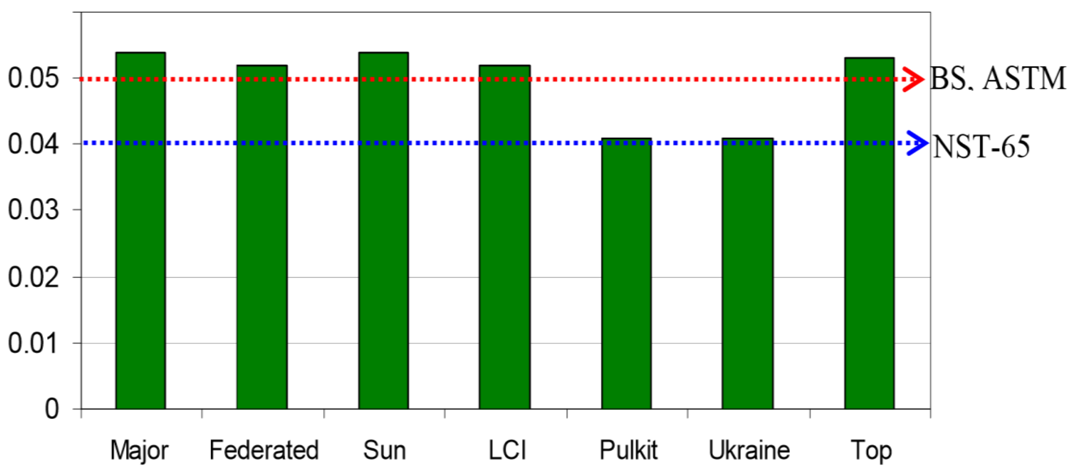

Fig. 5. Sulpur(S) contents in steel specimens.

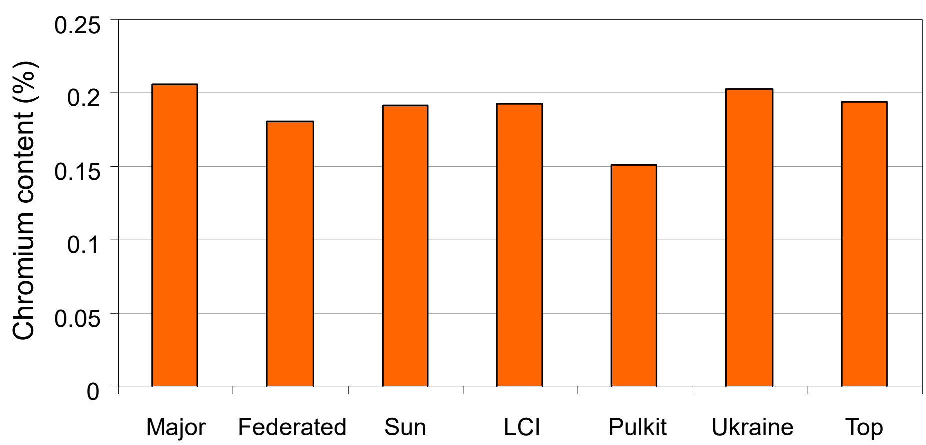

Fig. 6. Chromium(Cr) contents in steel specimens.

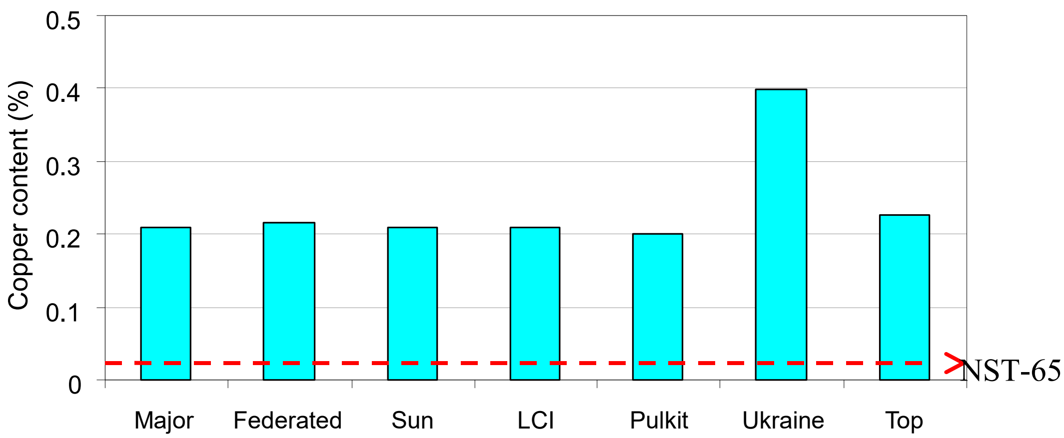

Fig. 7. Copper (Cu) contents in steel specimen.

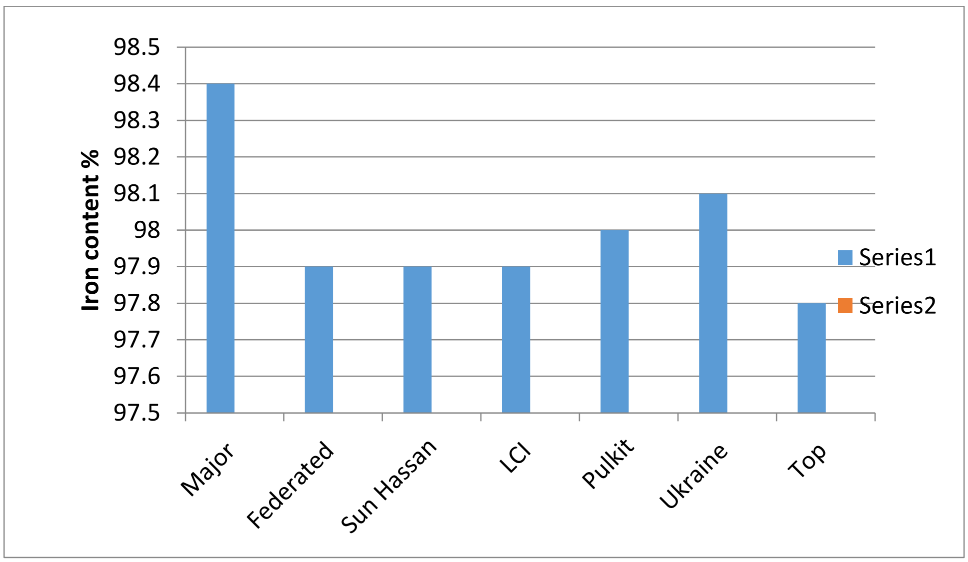

Fig. 8. Iron(Fe) content in the steel specimens.

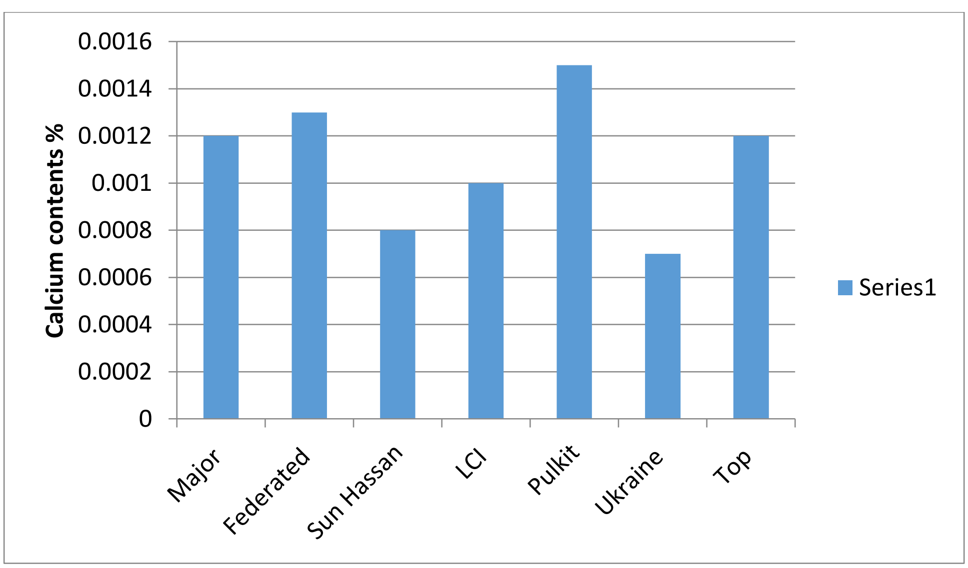

Fig. 9. Calcium (Ca) content in the steel specimens.

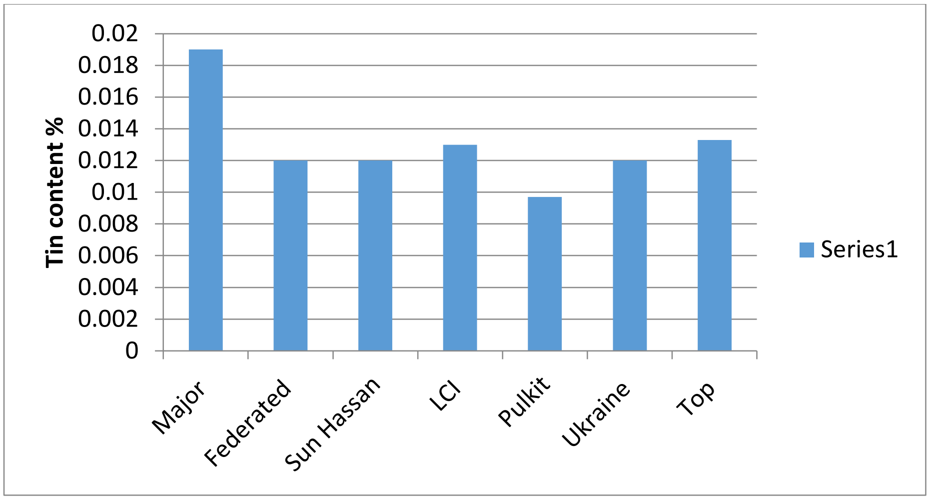

Fig. 10. Tin (Sn) content in the steel specimens.

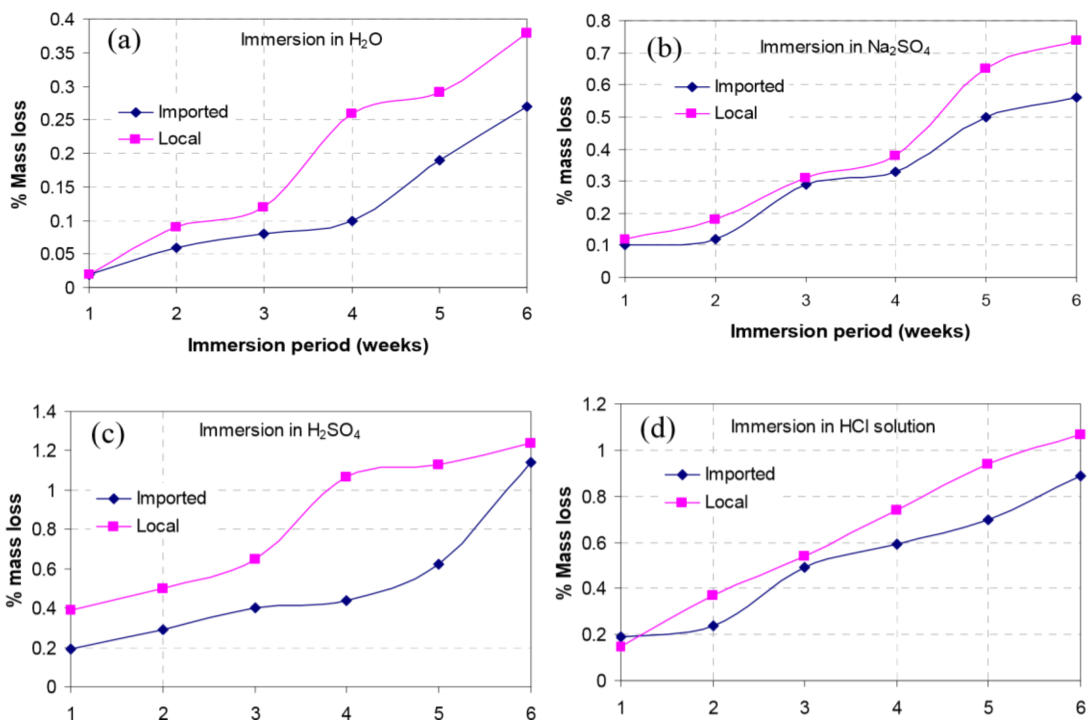

Fig. 11. Loss in mass of local and foreign steel reinforcements in different environments.

4. Conclusions and recommendations

The chemical analyses of the steel samples revealed that the imported steel samples from Ukraine produce carbon contents 0.202% fall within the NST-65-Mn, ASTM A706 and BS 4449 and specifications of 0.35%, 0.3% and 0.25% maximum values respectively.

Among the locally produced steel bars, carbon contents of specimens from Sun Hassan and Top steel (0.239 – 0.249%) satisfied BS 4449 (2001), while all except Federated and Pulkit met the ASTM requirement for carbon content. It is therefore evident that the strength of Federated and Pulkit steel specimens were enhanced at the expense of weldability and ductility.

All the steel rebars, local or imported, produced from the investigated sources are within the specifications for silicon.

All the steel specimens were much lower than the maximum specified values for Manganese. The tensile strengths of these specimens are more likely not to be extremely enhanced.

The phosphorous contents of all the specimens were higher than the maximum limits indicating the presence of impurities.

All steel specimens except those from Pulkit and Ukraine exceeded all maximum sulphur limits major international standards.

All the steel rebars types – local, TMT and imported far exceeded the 0.025% limit of copper content.

It can be concluded that virtually all the steel types contained different degrees of impurities.

All the steel bars experienced deterioration due mass loss characterized by colour change in all the solutions except NaOH solution where no visible reaction took place.

The percentage losses in mass, YS, UTS and EM for imported were 0.37%, 2.70%, 1.85% and 2.70%, while local bars had 0.51%, 3.0%, 2.17% and 3.0% respectively. The effect of HCl on the studied steel rebar types was the second most severe after the H_2SO_4. The ratio of the severity of local to imported steel rebars in water, Na_2SO_4, H_2SO_4 and HCl were 1.59, 1.26, 1.79 and 1.20 respectively. The average percentage losses in mass were 0.37% and 0.51% for imported and local bars respectively. At the end of the 6-week immersion of steel bars in Na_2SO_4 solution, local bars had over 30% mass loss higher than the imported bars.

5. Recommendations

The chemical constituents of steel rebar types have actually revealed the deficiencies and level of impurities in both the local and imported steel for concrete works. This has actually created a window for stakeholders – research, academics, industry and regulatory agencies - through which fundamental problems should be addressed.

References

[1] Amobi CO. Pro-active measures to avoid failures and collapse of buildings in Nigeria. J Niger Inst Build 2006;13:25–9.

[2] Arum C, Babatola JO. Failure of Building Structures, Causes an Preventive Measures. Proc Tech Sess Annu Eng Week Niger Soc Eng Akure 2006:50–61.

[3] Ayininuola GM, Olalusi OO. Assessment of Building Failures in Nigeria: Lagos and Ibadan Case Study'. African J Sci Technol 2004;5.

[4] Olusola BA, Opawole A. Causes of building failure in Nigeria. J Build Apprais 2009;4:279–86.

[5] Kolade OO. Characterization of steel reinforcement bars in the Nigerian markets and performance evaluation in concrete structures, M. Eng thesis, unpublished report submitted to Department of Civil Engineering, Federal University of Agriculture Abeokuta, Nigeria 2014.

[6] British Standards Institution, Code of Practice for Structural Use of Concrete. BS 8110: Part 1, London, British Standards Institution 2004.

[7] Kareem B. Quality verification of made in Nigeria steel bars. J Sci Tech Res 2006;5:33–6.

[8] Nwabuokei SO. “The Nigerian Steel Industry: Delta Steel Company Experience,” A paper presented at the Annual Lecture of the School of Engineering and Engineering Technology, FederalUniversity of Technology, Akure 2007.

[9] Kareem B. Tensile and chemical analyses of selected steel bars produced in Nigeria. Aust J Technol 2009;13:29–33.

[10] https://collegegrad.com/industries/steel-manufacturing (2019) n.d.

[11] British Standards Institution, Structural use of steelwork in building code of practice for design – rolled and welded sections, BS 5950, Part 2. London, British Standards Institution, 2001. n.d.

[12] British Standards Institution, Specification for cold reduced steel wire for the reinforcement of concrete. BS 4482, London, British Standards Institution, 1985. n.d.

[13] Singh B, Kaushik SK. Influence of steel-making processes on the quality of reinforcement. Indian Concr J 2002;76:407–12.

[14] Topçu IB, Karakurt C. Properties of reinforced concrete steel rebars exposed to high temperatures. Res Lett Mater Sci 2008;2008.

[15] Timoshenko SP, Gere JM. Mechanics of Materials, PWS Publishing Company, London 1997.

[16] Ede AN, Egunjobi EO, Bamigboye G, Ogundeji J. Assessment of quality of steel reinforcing bars used in Lagos, Nigeria. Int Res J Innov Eng 2015;1.

[17] Rocha J de L, Pereira R dos S, de Oliveira MCL, Antunes RA. Investigation on the relationship between the surface chemistry and the corrosion resistance of Electrochemically Nitrided AISI 304 stainless steel. Int J Corros 2019;2019.

[18] Foley RT. Role of the chloride ion in iron corrosion 2013.

[19] American Society for Testing and Materials, Specifications for chemical contents of steel fibres, ASTM A 706/A706 M, 2013 n.d.

[20] Nautiyal A, Qiao M, Cook JE, Zhang X, Huang T-S. High performance polypyrrole coating for corrosion protection and biocidal applications. Appl Surf Sci 2018;427:922–30. doi:10.1016/j.apsusc.2017.08.093.

[21] British Standards Institutions, BS 4449, Carbon Steel Bars for the Reinforcement of concrete” London, pp.1- 17, 1997. n.d.

[22] Nigerian Standard, NST 65-M, Raw Materials and Specifications for Federal Government Steel Companies, 1st Ed. Ministry of Power and Steel. NST- 65 - Mn, 1994. n.d.

[23] Kankam CK, Adom-Asamoah M. Strength and ductility characteristics of reinforcing steel bars milled from scrap metals. Mater Des 2002;23:537–45. doi:10.1016/S0261-3069(02)00028-6.

[24] Basu PC, Shyiamoni P, Roshan AD. Characterisation of steel reinforcement for RC structures: An overview and related issues. Indian Concr J 2004;78:19–30.