FAILURE ANALYSIS OF STEEL REINFORCEMENT IN COLLAPSED BUILDING IN NIGERIA

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MEng/SIPET/2018/8759

DEPARTMENT OF MECHANICAL ENGINEERING

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ABSTRACT

This research is based on worldwide concerns about the failure effect of mechanical properties in the reinforced steel bars gotten from building collapses in Nigeria. This work was investigated 12 collapsed building sites across Nigeria with the total number of 36 samples of reinforced steel bars 12 millimeter (mm) diameter being collected from the site in the cities of Lagos, Abuja, Jos, Uyo, Ibadan, Port Harcourt, Edo and Kano. For the strength of material analysis, each of the 12 samples of 12 mm diameter was considered for laboratory test. The results present the average values from each location of collapsed building and reveal that 100 % of reinforced steel from all collapsed building sites visited failed the standard tests. The significant factors from further demonstration to what the structural failure were also identified by analysis of microstructure and hardness techniques through the means of scanning electron microscope (SEM) and energy dispersive x-ray spectroscopy (EDS). Both predicted the presence of high weight percent (wt. %) concentration of carbon (0.51 %), phosphorus (0.71 %), sulphur (0.86 %) and oxygen (6.48 %) which proved brittle nature of the steel. Conclusively, the implication of the findings from this thesis confirms the failed steel reinforcement as one of the major contributions to building collapses.

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ABBREVIATIONS, SYMBOLS AND SUBSCRIPTS

ABBREVIATIONS	**FULL MEANING**
ASTM	American Society for Testing and Materials
BCPG	Building Collapse Prevention Guide
BSI	British Standards Institution
COREN	Council for the Regulation of Engineering in Nigeria
EDS	Energy Dispersive X-ray Spectroscopy
FCDA	Federal Capital Development Agency
NIS	Nigerian Institute of Steels
NSRMEA	National Steel Raw Materials Exploration Agency
SDG	Sustainable Development Goals
SEM	Scanning Electron Microscope
SON	Standard Organization of Nigeria

SYMBOLS **UNITS**

σ	Tensile Strength	N/mm^2
ð	Yield Strength	N/mm^2
P	Applied Load (Force)	N
F	Breaking Yield Load	N
A	Cross-sectional Area	mm^2

SUBSCRIPTS

o	Instantaneous
u	ultimate

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

The persistent cases of building collapses in Nigeria are on the increase (Ede, 2010 a). These collapses which can be termed as structural failure has been studied, and accused the unqualified personnel for using inappropriate design and substandard materials in building and other structural constructions (Olanitori, 2011). The rate at which it happens in Nigeria, demands prompt intervention, not discounting the unimaginable trauma each time building collapsed. There are approaches which can be used to analyze these effects of failures especially that of steel reinforcement in collapsed buildings (Almarwae, 2017). Therefore, this study was carried out in order to analyze the steel reinforcement.

The major principle of analyzing was based on visitation to different twelve locations of collapsed buildings. In the course of this research, different tests were carried out on steel reinforcement samples gotten from collapsed buildings. The laboratory tests were assessed in the following scopes: Tensile strength, Yield strength, Hardness, Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscope (EDS) tests on each sample from different locations of collapse buildings as stated: Two sites at Abuja (ABJ 01 and ABJ 02), Three sites at Lagos (LAG 01, 02, and 03) and a site at the following; Anambra (ANB), Edo (EDO), Ibadan (IBD), Kano (KAN), Port Harcourt (PHC), Adamawa (ADM) and Plateau (JOS).

What causes the frequent building collapses a case study of Nigeria? This study attempts to carry out the tensile, hardness and EDS tests on each steel samples collected at the collapsed building sites as listed above. These sampled steels were characterized by the parameters listed to evaluate the causes of building collapses in Nigeria.

1.2 Statement of the Research Problem

The reoccurrence of building collapses has been on daily basis (Obot and Archibong, 2016). In the revised course of most of the researchers' works, it can be inferred that they were only based on a matrix of the structural component of a building such as concrete analysis (Adetoro and Oladapo, 2017).

Akande *et al.* (2016) stated through the data released that the problem in analyzing the building collapses is such that large number of researchers mostly concentrated on the civil (concrete) analysis without further research on the structural steel reinforcement and most researchers that torches the aspect of steel reinforcement, were not actually advanced in the analysis of the reinforced steel.

In course of this study, there are two approaches to be considered that take the results further above the results achieved by the other researchers; so as to achieve the desired results in order to reduce, prevent or avert this ugly problem.

i. This study presents the evaluation parameters such as tensile strength, hardness, the yield strength, the detailed chemical composition of the failed steel samples and the corresponding detailed morphology of the microstructures of each failed samples from each collapsed building site.

ii. This study further the research by coverage 12 different locations of collapsed building sites in the six geopolitical regions including Federal Capital Territory, Abuja in Nigeria, such as Lagos and Ibadan (South-west), Edo and Port Harcourt (South-south), Anambra (South-east), Abuja (FCT) and Plateau (North-central), Kano (North-west) and Adamawa (North-east).

1.3 Aim and Objectives of the Study

1.3.1 Aim of the study

The aim of this thesis work is to carry out the failure analysis of steel reinforcement in collapsed buildings in Nigeria.

1.3.2 Objectives of the study

The following objectives through which the aim of the thesis will be achieved are highlighted as;

i. To evaluate the properties of reinforced steels used in collapsed building through the mechanical failure analysis such as Tensile strength and Hardness test on the failed steels.
ii. To characterize the chemical composition of each failed steel in collapsed building sites at different locations.
iii. To evaluate the effect of microstructures on the strength of the steels used for building construction in Nigeria.

1.4 Justification of the Study

This study is to solve the problem of how building collapses in Nigeria can be averted. The outcome of the failure analysis used in this study will be economically of benefit to steel manufacturers, the builders, mechanical, civil, materials and metallurgical engineering and all other stakeholders such as Building Collapse Prevention Guild (BCPG), Standard Organization of Nigeria (SON), Nigeria Institutes of Steels (NIS), Council for the Regulation of engineering in Nigeria (COREN), by been incorporating a standard, essentially in purpose, production, planning, use and control of steel in Nigeria. The observation and consideration of the guided rules and regulations significantly assists to further appreciate the properties of steel products in order to prevent the future occurrence of building collapses in Nigeria. With the outcome of this study, many live and properties will be protected.

Then, the result of the findings would provide a better and standard engineering skill of individual metallurgical companies by acquiring the professional and able technical knowledge to improve the manufacturing processes and taking the steel manufacturers to a greater height.

Finally, this study would be of importance to the policymakers at various levels by serving and promoting the guide on how to create suitable policies that will help and improve the existence of the indigenous steel manufacturers. The order of the rules and regulations will then transform the indigenous steel manufacturers to multinational metallurgical steel plants, so as to support and improve the national economic growth and development.

1.5 Scope of the Study

The scope of this study is limited to five areas of findings;

i. To carry out analysis on steel reinforcement only excluding the matrix of the composite materials (concrete).

ii. To characterize the chemical composition of failed steels in collapsed building sites.

iii. To carry out the strength and hardness tests on the failed steels in collapsed building sites.

iv. To analysis the microstructures of the failed steels in collapsed building sites.

v. The areas of research locations cover only twelve sites in all six geopolitical zones with the Federal Capital Territory (FCT), Abuja inclusive.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Review of Previous Work

Studies on the failure analysis as the major effects on different mechanical properties and microstructure of steel collected from collapsed structure sites in Nigeria (especially in the areas of building collapses) have been expanded through various works. Researches abound in literatures on causes of building collapse and prevention in Nigeria indicates that at the onset of the nineteenth century, the global world witnessed the transformation of structural materials with better mechanical behaviour. This is of no exception to the Nigerian building and construction industry. The building construction industry’s uses steel to enhance the strength and thereby improve the durability of the structure. Attempts have been made in series of researches for the standard adoption of mechanical testing of steels in relation to tensile strength, and yield strength vying further expands this area of study.

The report of the Federal Capital Development Agency FCDA was quite worrisome on the inability of government agencies to properly prosecute building collapse cases due to lack of legal instrument, which the NIS should have provided. It furthers explained the consequences of no conviction has been recorded and culprits, including building professionals, walk free (Akande *et al.*, 2016). With the numerous deaths recorded yearly in Nigeria as a result, the problem has become a source of great pain to the economy with enormous loss of human and capital assets. Furthermore, a collapse of a hospital structure under construction in the Gwarimpa area of the Federal Capital Territory, Abuja, located near the premises of Federal Ministry of Works and Housing could have been avoided if professionals handling the project were guided by a functional code. Contrary to the earlier scenario, the FCDA took the necessary steps to pull down the building of Nigerian Union of Journalist located at Utako, because it failed the required standard code integrity test.

Generally speaking, there is a lot of confusion. In most of the building constructions where quality and standard codes are very important, builders and construction companies rely on international inference codes. Technically, no operational codes exist here in Nigeria; in the simple sense that it is not the code that everybody agrees on and uses. Therefore, here are some of the reviews;

Certainly, it is not unusual for building to collapse in Nigeria. Materials used in building construction are often substandard and the enforcement of regulations is lax as stated by the Lagos State Building Control Agency at the collapsed site of a 3-storey building in Oshodi, Lagos (Odusote *et al*., 2019). In a previous case, a 5-storey building collapse in

Lekki, Lagos killed at least 34 people in 2013. Recently, the report that a 3-storey building collapsed with many victims trapped under the wreckage in Jos, Plateau while about 150 people died at Reginers Church in Uyo, Akwa Ibom when the newly built auditorium collapsed.

Also, Ede (2010 a & b), reported the ugly incident of a 3-storey building of Foursquare Gospel Church, Abuja collapsed in October, 1999. Further buttressed his points, Nigerian Building and Road Research Institute (2011) reported a building collapsed at Kano in July 1991 with a lot of lives and properties lost. The guest house of Synagogue Church of All Nations in Lagos with multiple-storey collapsed and no fewer than 115 deaths recorded. Another report had it that 272 lives were lost in incidents of building collapses within 7 months of year 2017. In the annual report of 2017 by the Federal Ministry of Power, Works and Housing, revealed that 54 building collapsed across the country between 2012 and 2016, in which a tribunal committee set up by the ministry made a huge record of 135 cases of building collapses in Lagos alone between the year 2007 and 2013.

A different case of building collapse has been reported by a numerous number of researchers in Nigeria. Adebowale *et al*. (2016) researched extensively and confirmed that the reported building collapses were based on the poor quality of material and management challenges contributing to the collapse building in Nigeria. Obviously, it was concluded that building collapses in Nigeria cut across the country with its extremely high effects on human lives and properties. Olajumoke *et al.* (2009) reported some cases of building collapses in Osun and reviewed that it was not considered as a fault of the steel only but also other civil materials, while Akande *et al.*(2016) reported on the causes and effect of building collapse in Lagos as ordinary civil management lapses. Further in the course of review, Adeniregun (2010), Kingsley (2010) and Bukola

(2010) were also consolidated on outcomes being made by most of the researchers that the incidence of building collapses in Nigeria posed a great risk to human lives and properties, while concluded on the review of the steel reinforcement as the major cause of building collapses.

Oke (2015) examined and reviewed the causes and effects of building collapse in Nigeria and stated the procedural formulation that the function to prove were based on lack of maintenance culture, improper design and poor quality of materials. Hence, concluded that overloading of materials beyond capacity accounted for 94 percent (%) causes of building collapse in Nigeria. In a related review of opinion, Hamma and Koulder (2017) attributed the dominant occurrence of building collapse to structural failure, carelessness, poor workmanship, poor supervision, poor materials and quack engineers. Meanwhile, it is a factual point that the work typically pointed out that inferior materials, incompetent engineers and poor structural designs accounted for modal occurrence. The fundamental inabilities to accept these attributions, as clearly stated in their researches were roadmap to national disaster.

Oyedele (2018) researched into control measures of building collapse in Lagos, in his re-evaluation, low quality of reinforced steel, lack of integrated approved national codes that relate building construction and materials employed was responsible for the building collapse in Lagos. The approved and established national codes supported by law should be the top priority as the conformity to Sustainable Development Goals (SDG) agenda. Currently in the Nigeria system, building constructions were determined by trial and error, and largely based on experience which affect the sustainability to optimize the structural procedures, and forms the exact consequence at national level.

Recently, Wasiu *et al*. (2018)in another development reported causes of building collapse and prevention in Nigeria, in their findings poor concrete design contributes to the major failure of building in Nigeria. Numerical analysis of the research, also, evaluated that a lot of citizens has lost their lives to building collapse occurrence for almost 50 decades. It is helpful not only in safety of lives and properties but also in propagating the best design sequence for construction of buildings. It has been reported further, that an incidence of building collapse in Nigeria from December 1976 to August 2006, analyzed 452 cases of death recorded in some of the cities of Ondo, Oyo, Kaduna, Borno, Rivers, Lagos, Sokoto, Kano, Kwara, Abia, Ogun and Adamawa. Therefore, there is need to compliment and work more on the outcome situation of the researches to salvage this serious national disaster; building collapse.

Omenihu *et al*. (2016) reported that about 607 lives were lost due to the building collapse in Nigeria between 2007 and 2016. Analyzed this report, it is more difficult for Nigerians to sleep peacefully under their roofs for the fear of building collapse. In correlation to global population, Omenihu *et al*. (2016) did an extensive research on mathematical analysis of casualties from building collapses in Nigeria in the period of 1971 to 2016, in their findings, 175 building collapse incidence were recorded while a total number of 1,455 Nigerian citizens lost their lives in the ugly incidence of the building collapse. What a great lost to a developing nation of ours?

In physically sampled review, the core of steel bar is always available in different dimensions as diameters of 8, 10, 12, 16, 20 and 25 millimeters (mm). Different grades of steel bars are available depending on the mechanical properties as tensile-yield strength of the materials. The effects of various parameters accompanied mild steel at higher strength are normally used in order to compliment the effect of strength of the concrete in thin columns and large span beams. It has been verified and confirmed by Chendo and Obi (2015) that due to the effects of economic downturn biting harder at the moment in the country, 12 mm steel bars are being substituted for other higher dimensions especially 16 mm for construction of high-rise buildings which served as a basis for structural failures in Nigeria. What a peculiar compromise of standard in building construction in Nigeria? To redeem the situation, it was high time structural, building and materials testing laboratory intensified efforts to ensure that building materials being used for construction are tested and contractors adhere to national building code specifications. This is the most comprehensive achievement that can be recorded in the building construction sector of the economy.

Odusote and Adeleke (2012) worked colossally on the substance organizations and the microstructures of steel bars support acquired from various imploded constructing areas. Over the span of their research, the carbon substances of the steel bars are higher in locally made steel (NIS, 1992) than BS4449 (BS, 1997) and that of ASTM706 (ASTM, 2001), however closer in worth to the Nst-65-Mn standard. Additionally, the sulphur (S) and phosphorus (P) substance are higher than the BS4449, ASTM706 and Nst-65-Mn principles, while the presence of manganese substance in the steel are very lower. The examined inspected bars uncovered that the hardness esteems are higher than suggested BS4449 standard yet lower than Nst-65-Mn standard with the sign that the weak globules of Fe_3P and FeS were seen inside the design. The examined supporting bars results recommended that the tested materials are fragile and subsequently contributing essentially to the breakdown of the structure structures. In the interim, the exploration was completed under the Optical discharge spectrometer for the synthetic examination, while the microstructure was inspected utilizing an optical microscopy.

Ede *et al*. (2015) in their professional viewed and urged the builders and contractors to embrace and use only building and structure materials for construction with certified quality steel and casting products that can withstand the devastating impacts of shocks and quakes amid increased rate of collapse of buildings in Nigeria. This made the effort to be also appreciated when researched into assessment of quality of steel reinforcing bars used in building construction in Lagos metropolis of Nigeria. The result of yield strength shows that 10 mm, 12 mm, 16 mm, 20 mm and 25 mm gives 70 %, 63 %, 54 %, 53 % and 53 % respectively of the samples tested and met the BS4449:1997 Code Specification standard of 460 N/mm^2. But 8mm diameter samples, failure analysis, effects of microstructure of the samples and hardness examination were excluded and also their research was only within the city of Lagos.

Adzora *et al*. (2019) demonstrated that the steel weldment in tough assistance applications has provoked cautious determination of welding consumables and current, for the welding of metal. Weld dots were kept with cathodes utilizing current of around 90 amperes. From there on, the welded examples were machined to the necessary measurements for hardness, sway and rigidity tests, and a standard metallographic strategy was applied to inspect the microstructure shaped across the steel. The outcomes showed that great hardness and longitudinal elastic properties were acquired from welds made with E7016 cathode, while unrivaled effect strength and percent stretching was gotten in welds made with E7024 terminal. It results that, every cathode type, the hardness, yield strength, and rigidity diminished with expanding welding current yet the effect strength and percent prolongation expanded likewise. It then, at that point inferred that, the impact of welding consumables on the mechanical properties of miniature alloyed steel weldment by utilizing safeguarded metal circular segment welding measure expanding interest for better of steel quality.

Yunlong *et al*. (2012) expressed that the mechanical assembling cycles of three sorts of roll center utilized malleable irons have been researched comparable to systematical tests. Consequently, impacts of the proportion of Carbon/Silicon (C/Si), pig iron, nodularizer and alloying strategy on the microstructure and mechanical properties of the hefty area flexible iron have been examined. It then, at that point presumed that when treated with Magnesium (Mg) in addition to Antimony (Sb), top notch nodular castings can be delivered. Thus, Antimony (Sb) demonstrated the huge impact in the morphological treatment of graphite, regardless of whether much enemy of spheroidizing combination components are remembered for the pig iron.

Alaneme *et al*. (2019) demonstrated that the primary attributes, mechanical and wear conduct of mix cast Al-Mg-Si compound based composites supported with various weight percent of steel, steel-graphite cross breed blend, and SiC particles were examined. In the interim, the particular strength and crack sturdiness similarly pursued a similar direction concerning steel fixation with strain to break, the special case where somewhat under 4 % as noticed. For the half and half supported composite pieces containing steel and graphite, every one of the mechanical properties diminished with expansion in graphite content and followed the composite built up steel. From this exploration, the clear upsides of malleability and strength in aluminum fortifications were better than the SiC supported composite and attributed to further developed grain refinement and interface holding, and the intrinsic flexibility of the steel particles that provoked for built up steel employments.

Millogo *et al*. (2012) uncovered that the pattern over the top carbonation came about of the event of heterogeneous microstructure is characteristic of microstructure grain coarsening because of the expanding the consistency of iron pinnacle force demonstrated that hematite was not lime while the calcite gave the response among portlandite and carbondioxide. Be that as it may, Oguzie *et al*. (2012) in any case expressed that the erosion of iron in some random climate might continue toward various components and showed in the inhibitive impact of the corrosive concentrates on the consumption of gentle steel as far as the weight reduction of carbon steel in procedural interaction with uninhibited and repressed substance of a molar of Hydrochloric (HCl) fixation.

Stradomski *et al*. (2013) further the examinations concerning the issue of steel breaking throughout steel castings measure. It very well may be gathered that instrument of intergranular and decohesion, due happens in the creation interaction of hot breaking. In the meantime, Kulka *et al*. (2012) revealed that an assortment of underlying components is definitive for hot breaking commencement, which exclusively rely upon substance organization of the cast steel. In the survey of this outcome, the breaking of the great carbon device cast prepares inside the net of optional cementite and ledeburite encouraged along the limits of set grains which dependent on mechanical properties at controlled temperature of about 1050 degree Celsius (°C) (1323 K) uncovered the impact of exceptionally low strength in high-carbon cast prepares.

Sinaie *et al*. (2014) put forth attempt to demonstrate their cases in the comparing strain levels to out-past a definitive strength of the material. Notwithstanding, the outcomes showed that the hardness of the steel expanded as per expansion in steel particles to weight proportion. In the mean time for the monotonic stage, their joined effect on ensuing mechanical properties of primary steel is uncovered that high temperature chiefly contributes toward strength decrease just as for a similar scope of steel compound fixation, a definitive rigidity additionally expanded with expansion in steel weight proportion. In the due thought of the examination, these strength esteems were all higher than that of supported steel by unanimity edge yet significantly flopped every one of the tests as explored.

Nwachukwu and Oluwole (2016), Alamu and Aiyedu (2003) did not yield work to additional dealt with the impact of moving cycle boundaries at various moving strain rates in which the rate (%) absolute calculation disfigurements and complete the process of moving temperatures on the mechanical properties of hot moved not really set in stone. The acquired trial results were contrasted and existing writing on moving carbon prepares for the boundaries, for example, the rigidity, yield strength, hardness, young modulus of flexibility, durability, bendability, rate (%) prolongation and rate (%) decrease in space of the hot-moved item. The exploration results showed that the moving system boundaries strikingly impacted the mechanical properties of steel. It was presumed that expanding the moving strain rate from 6.02851103 s^{-1} to 6.10388103 s^{-1}, utilizing rate (%) absolute disfigurements of almost 100 % and complete the process of moving temperature of 958 °C improved the mechanical properties of steel.

Be that as it may, Zhang *et al*. (2012) detailed that high strength compound prepares is helpless against the impacts of debasement initiated by the climate attributable to its synthetic piece and most metal combinations do not really appear to be more unsafe than those made of valuable metal. In the mean time, Chandrashekar *et al*. (2012) molded that because of its high strength, low combination steel is a conceivably reasonable support for a wide scope of uses in the development business.

Oliveira *et al*. (2018) introduced the use of a natively constructed technique for assembling of mechanical new parts introduced in hardware to deliver steel pole outlines. It uncovered that the imported bar part chose here were because of its fundamental significance for the appropriate elements of the hardware, the power of administration stacks, its significant expenses and non-accessibility. The examination additionally guaranteed that the necessary edges delivered from steel pole would then be able to be considered for the assembling of bars and its parts dependent on near benefits as far as mechanical properties, essential creation, and microstructure to the unfamiliar ones. The principle point was to decrease the expenses and conveyance time for the procurement of the bar part, have a sufficient load of it, and affirmed that the assembling of the pole parts is a feasible technique.

Oyelade *et al*. (2013) verified the capability of strength available for the steel reinforcement in building and other structural construction. It aims to provide the necessity that can reduce the incessant reoccurrence of structural failures such as building and bridge collapses, due to inappropriate design and substandard steel reinforcement applications. The tests analyzed were based on microstructure, tensile and flexural strengths of steel reinforced beams. It can be deduced from the analysis that two out of six sampled steels (both local and foreign based sources) sustained the minimum requirements for high carbon steel application. Hence, all the foreign based source steels failed the 'elongation' minimum requirement. More so, all the sampled steels tested failed the chemical and metallurgical standards while considered carbon contents and its equivalent values. In the course of carried out experimental analysis on chemical composition of the sampled steel, Optical Emission Spectrometer (OES) was considered. However, Mouhyi *et al*. (2012) in their separate research reported that every one of the unfamiliar based steel examples tried showed a better burden avoidance trademark thought about than the privately sourced steel tests. From the consequences of this examination, it would thus be able to be found that all building up steel assigned as high return ought to be exposed to additional testing before use in order to guarantee consistence with the overall public standard codes.

Gowda *et al*. (2017) broke down a report that consumption (climate prompted debasement) frequently happens in steel support as an electrochemical interaction, which prompts slow misfortune in mass throughout some undefined time frame when exposed to delayed openness in a forceful climate. It tends to be induced that the prompt impacts of the erosion, represent an adverse consequence on steel organizations in the constructions, incorporates decrease of the cross segment. Additionally, Peng *et al*. (2012) further led tests to examine the weariness properties of steel in the wake of being exposed to uniform climate incited corruption or consumption.

Shi *et al*. (2012) examined the synthetic piece, microstructure and mechanical properties of steel and concrete mortar utilized in built up concrete. The arrangements and mechanical properties of the privately delivered steel were investigated to affirm their potential for applications in the development business. Besides, the examination expressed that two concretes delivered and found in the Nigerian market were contemplated. Over the span of their investigation, the compound structures of the still up in the air utilizing X-beam Fluorescence (XRF) and X-beam Diffraction (XRD) procedures. For the all around performed analyze, the concretes were blended in with standard waterway sand to create mortar with very much controlled blended extents. In the interim, the setting time and sufficiency of the not really set in stone alongside their compressive and flexural qualities with the ramifications of fundamentally enhancement for the wellbeing and dependability of African buildings.

Rekha and BupeshRaja (2010) reported that the metals and alloys are applied in wide area of application in engineering and other sectors. The effects of mechanical properties on the metals and alloys are subjected to their microstructure. Hence, the microstructure analysis is studied using conventional optical microscope along with

Scanning Electron Microscope (SEM) and other high end equipment suitable for metallurgical processes. Also, boost the research by using computer soft-wares (digital image and vision processing) technologies to analysis the microstructure.

2.2 Theoretical Background

2.2.1 Process of steel rolling

In the assembling system of prepares, Alamu and Aiyedun (2003) broke down that realize that all the creation stages have critical impact on qualities of the steel. The nature of fundamental materials utilized in moving the steel and its assembling interaction are altogether needed to create the best quality steel. The course of steel moving first to consider in quite a while of nature of metal piece utmost affects the exhibition of steel when re-rollables are utilized. The gentle prepares are moved from general carbon steel billet without embracing any uncommon means or granting further strength. In the interim, for in excess of 50 % of the prepares handled from the re-rollables fabricated of the piece materials, for example, scrap rails, vehicle scrap, safeguard scrap, defectives from steel plants, and scrap created from transport breaking or disposed of designs are clashing viewpoints which demonstrate that specific degree of refinement of the arrangement of steel is essential.

The steel roll best desired refinement can be suitably achieved with the use of an Electric Arc Furnace (EAF), which unfortunately is not being employed here in Nigeria due to prohibitive economy cost of production as reported when visited Ajaokuta Steel Company. Alternatively, induction furnace is available for the production of steel from scraps. The molten scrap from the induction furnace cannot yield sufficient refinement to produce billets of desired quality. Nigeria as a case study, large quantities of steel are now producing from metal scraps. Hence, both producers and end-users of steel continue to face the problems posed by the poor quality of these steels.

The researches have showed that the steel, generally produced by hot rolling, establish the majority of about 90 % by weight of all building development steel profiles regularly utilized in development and other designing works. This investigation detailed an immediate relationship presence between steel's microstructures and its mechanical properties. Subsequently, there should be a collaboration advancement of an applicable boundary model in steel as one of the successful strategies for its mechanical properties improvement. Observational assessments of techniques for creating hot moved prepares demonstrate an extreme takeoff from the traditional moving practices. Against the sole reliance on substance synthesis change, accentuation is significantly positioned on the improvement of pertinent boundary that ensures progressed strength properties.

Through controlled and checked control of metallurgical variables, higher qualities are prompted in the steel based on better comparing microstructures created. According to Ede *et al*. (2015) the low carbon steel produced in Nigeria exhibit low strength characteristics and possesses high percent of carbon content. In correlation to that report the world's average specification for high yield steel is 460 MPa, as against the NIS of 420 MPa, BS4449 of 500 MPa and ASTM of 415 MPa in reference to Odusote *et al*. (2019).

2.2.2 Composition of steel

An addition of carbon in little amounts to appreciable amounts of iron forms steel. The impact of carbon on mechanical properties of iron is much conspicuous than other alloying components. Variety of the measure of alloying components and the type of their quality in the steel influences the mechanical properties (hardness, malleability, and elasticity) of the subsequent steel. Steel contains high percent of carbon content is harder and more grounded than iron.

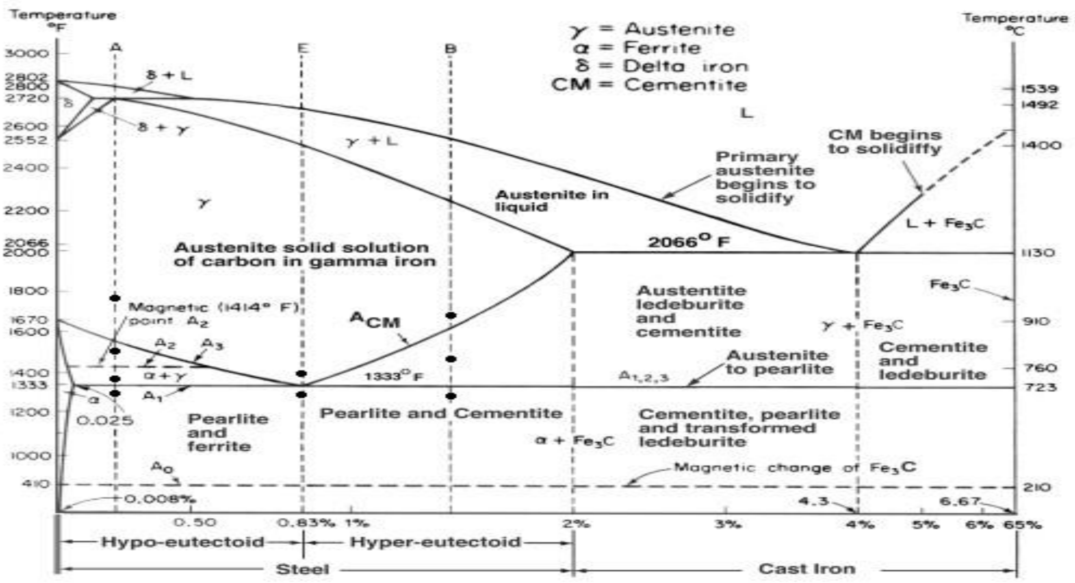

Figure 2.1: The iron–iron carbon (Fe-FeC) phase diagram

(Source: Callister, 2007)

As shown in Figure 2.1, striking increases in carbon content is not the only way to obtain increased strength of steels. Mechanical strength and ductility of steel can be improved even with low carbon content when proper processing mechanism is explored.

2.2.3 The iron–iron carbon (Fe-FeC) phases

i. The Austenite (γ): Austenite is a face centered cubic (fcc) material while considering carbon content, and stable at temperatures above 723 °C (996 K). It breaks up about 2 % carbon substance. In austenitic Cr-Ni prepares, the expansion of P can cause precipitation impacts and an increment in yield focuses. In solid oxidizing specialist, P causes consumption after strong arrangement treatment because of the isolation of P, at grain limits.

ii. The Pearlite: Pearlite is the combination of (grain-fine) ferrite and cementite organized in lamellar structure. It tends to stableat temperature below 723 $^{\circ}$C (996 K). The grain-fine pearlite is hard and works on mechanical strength in steel. This shows the higher the carbon content, the higher the pearlite content. In opposite response, if the cementite content builds, the ferrite content declines and thus the malleability are decreased.

iii. The Ferrite (α): Ferrite is usually a pure iron and stable at temperature of about 910 $^{\circ}$C (1183 K). The solubility of carbon content in ferrite depends on such temperature. All the same, Ferrite is mostly regarded as soft and ductile steel.

iv. The Cementite: Cementite can likewise be called Iron carbide (Fe_3C). At metastable harmony, cementite shows various blends of high carbon content and temperature. The steel part of the Fe-C stage covers the scope of 0 and 2.08 weight rate (wt. %) carbon. The cast iron part of the Fe-C stage covers the reach somewhere in the range of 2.08 and 6.67 weight rate (wt. %) carbon.

2.2.4 Classification of structural steel

Structurally, steel can be classified into:

i. Low alloy steels: These possess slowly cooled microstructures combination of iron and carbon contents namely pearlite, pearlite and ferrite, or pearlite and cementite.

ii. High alloy steels: These steels possess slowly cooled microstructures, with the combination of iron and carbon consisting either of martensite, austenite or ferrite and carbide particles.

2.2.5 Effects of alloying elements on steel

It is realized that prepares should contain alloying components and debasements related with austenite, ferrite and cementite. The impacts of consolidated alloying components and warmth treatment produce assortment of microstructures and properties. Comparable to alloying components, and as indicated by the connection with carbon, steel can be partitioned into two classes:

i. Carbide framing components: Elements like Manganese (Mn), Chromium (Cr), Molybdenum (Mo), Tungsten (W), Vanadium (V), Titanium (Ti) and Zirconium (Zr) go into strong arrangement in cementite at low fixations. At higher focuses, they structure more steady amalgam carbides. From all sign, Manganese just breaks up in cementite.

ii. Non-carbide-framing components: Some components as Nickel (Ni), Cobalt (Co), Copper (Cu), Silicon (Si), Phosphorus (P), and Aluminum (Al). They structure without carbide prepares.

CARBON: The carbon (C) content needs in the creation of steel decide the sort of steel that can be made (Alamu and Aiyedun, 2003). As the weight percent (wt. %) of carbon content in rimmed steel expands, its surface quality break down. Killed prepares (contain 0.15-0.30 % carbon) may have more unfortunate surface quality and require uncommon handling to accomplish surface quality similar to prepares with sequential carbon substance. It is normal more huge than some other alloying components. Carbon has a moderate inclination for full scale isolation during hardening, and has a solid propensity to isolate at the imperfections in prepares. A few outcomes demonstrated that Carbide framing components might communicate with carbon and structure amalgam carbides (Figiel *et al*., 2020). Carbon is the fundamental solidifying component in all prepares with the exception of the austenitic precipitation solidifying treated steels, overseeing prepares, and sans interstitial prepares. The impact of fortifying carbon in prepares can be portrayed as strong arrangement reinforcing and carbide scattering reinforcing. Likewise as weight percent (wt. %) of the carbon content expands, strength increments, and excellent dimensional control can be accomplished. Conversely, flexibility and weldability decline.

MANGANESE: Manganese (Mn) is tentatively affirmed in all prepares of about 0.30 % or more. Manganese is basically frail carbide, deoxidizer and desulphurizer which just disintegrate in cementite, and structures alloying cementite in prepares. Basically, it has a lesser propensity for full scale isolation than any of the normal components. Prepares contain manganese content above 0.60 % can not be rimmed, in which its properties well influences forgeability and weldability. More amounts of Manganese (above 2 %) in steel result incline toward breaking and contortion during extinguishing (Rozniata and Dziurka, 2015). Henceforth, its essence in prepares improves the presence of different contaminations to grain limits and initiates temper embrittlement as in phosphorus (P) and Tin (Sn).

SILICON: In the production cycle of steel making, Silicon (Si) is one of the significant deoxidizers utilized. In this manner, silicon content decides the kind of steel delivered. In framing, killed carbon prepares may contain Si up to a limit of 0.60 % while semi-killed prepares contain moderate substance of Si. Silicon breaks down totally in ferrite, in case it is beneath 0.30 %, and expanding its solidarity without extraordinarily diminishing pliability. Trial investigation shows that past 0.40 % Si, an uncommon lessening in flexibility is seen in plain carbon prepares. In the compound response measure, its blend with Mn or Mo produces more noteworthy hardenability of prepares (Rozniata and Dziurka, 2015). Throughout heat-treated, Si fills in as significant composite component, which expands hardenability, wear obstruction, flexible cutoff, yield strength, and scale opposition in heat-safe prepares. Si is a non-carbide previous component, and liberated from cementite or carbides (Klaput, 2015). The plan result makes it disintegrates in martensite and retards the deterioration of alloying martensite in the temperature district of 300 $^{\circ}$C (573 K).

PHOSPHORUS: The general hypothesis embraced as Phosphorus (P) isolates during cementing, is followed less significantly than C and S impact. Phosphorus breaks down in ferrite and expands the strength of steel. For the current creation measure, as the substance of P expands the pliability and effect durability abatement, and raises the cool brevity. (Sieczkowski, *et al*., 2015) it is useful not just in an exceptionally solid propensity to isolate at the grain limits, yet in addition aims the temper embrittlement of alloying prepares, particularly in joined arrangement with Mn, Cr, Mn-Si, Cr-Ni, and Cr-Mn prepares. Phosphorus plan likewise expands the hardenability and retards the disintegration of martensite-like prepares. The higher measure of P content is regularly determined in low-carbon free-machining prepares to further develop machinability. Phosphorus respectably expands strength and environmental protection from erosion in low amalgam (primary) prepares containing 0.1 % carbon. Stradomski *et al*. (2013) likewise uncovered through their exploration that the weak phosphor and carbide eutectics encouraged in the last stage hardenings were liable for breaking of castings made of steel.

SULPHUR: It was expected that expanded measures of sulphur (S) can cause red-brevity or hot-brevity because of the low-liquefying sulfide eutectics encompassing the grain in reticular style. Sulphur, in impeding impact on cross over malleability identical yields score sway durability, weldability, and surface quality particularly in the low carbon and manganese prepares, however slightly affects longitudinal mechanical properties. Sulphur has an exceptionally solid inclination to isolate at grain limits and causes decrease of hot malleability in compound prepares. In any case, sulfur content inside 0.08 – 0.33 % is purposefully added to free-machining prepares for expanded machinability (Rozniata and Dziurka, 2015). Sulphur further develops the exhaustion life of bearing prepares in the accompanying two ways;

1. It was accounted for that the warm coefficient on MnS incorporation is higher than that of lattice, yet the warm coefficient of oxide considerations is lower than that of network,

2. Moreover, MnS incorporations coat or cover oxides (like alumina, silicate, and spinel), subsequently decreasing the malleable anxieties in the encompassing network.

ALUMINUM: Aluminum (Al) is widely utilized as a deoxidizer and a grain purifier. For Al to shape exceptionally hard nitrides with nitrogen, it is normally an alloying component in nitriding prepares. It builds scaling opposition when added to warm safe prepares and combinations. In precipitation solidifying hardened steels measure, Al fills in as an alloying and maraging prepares (Royset *et al*., 2008). Likewise, Al fills in as the consumption opposition in low-carbon erosion opposing prepares. Al is quite possibly the best alloying components in controlling grain development preceding extinguishing. The basic disadvantage of Aluminum is an inclination to advance graphitization.

CHROMIUM: Chromium (Cr) is medium carbide previous. In the low course of Cr/C proportion range, just alloyed cementite $(Fe_3Cr)C$ structures. Chromium expands hardenability, oxidation obstruction, high-temperature strength, high-pressure hydrogenation, and scraped area opposition in high-carbon grades (Lukaszcyk and Augustyn-Pieniazek, 2015). Chromium carbides are hard and wear-safe and increment the edge-holding quality. Complex chromium–iron carbides gradually go into arrangement in austenite; in this way, a more drawn out time at temperature is important to permit answer for happen prior to extinguishing is refined. The presence of Chromium in prepares improves the presence of different contaminations to grain limits and actuates temper embrittlement like P and Sn.

NICKEL: Nickel (Ni) is a non-carbide-shaping component in prepares. Nickel raises hardenability. In compound blend with Cr and Mo, it produces more noteworthy hardenability, sway sturdiness, and weakness opposition (Rozniata and Dziurka, 2015). Nickel disintegrates in ferrite to further develop strength, even at room temperature. Nickel further develops the oxidation obstruction of Cr–Ni in austenitic treated steel (Ramkumar *et al*., 2020).

MOLYBDENUM: Molybdenum (Mo) is articulated carbide previous. It disintegrates marginally in cementite. Molybdenum carbides can possibly frame when the Mo content is sufficiently high. Molybdenum can instigate optional solidifying during the hardening of steel. It additionally works on the killed carbon steel of low-composite prepares at raised temperature (Klaput, 2015).The option of Mo creates fine-grained prepares, builds hardenability, and weariness. Composite prepares containing 0.20-0.40 % Mo or V presentation a postponed temper-embrittlement, yet can't dispose of it.

Molybdenum has an extremely impressive strong arrangement reinforcing in austenitic combinations at raised temperature.

TUNGSTEN: Tungsten (W) is a solid carbide shaped component. By thinking about the conduct of W, is basically the same as Mo in prepares. Tungsten marginally disintegrates in cementite. As the substance of W expansions in composite prepares, W shapes extremely hard, scraped spot safe carbides. It can actuate optional solidifying during the treating of steel (Klaput, 2015). It advances hot strength and red-hardness, and accordingly cutting capacity. It forestalls grain development at high temperature. In any case, W and Mo disable scaling obstruction.

COPPER: Modestly, Copper (Cu) expansion tends to isolate. Above 0.30 % Cu can cause precipitation solidifying. It expands hardenability. In case Cu is available in obvious sums, it is adverse to hot-working tasks. Contingent upon the drawback of surface quality, Cu misrepresents the surface deformities innate in re-sulphurized prepares. In any case, Cu in the abundance of 0.20 % further develops the oxidation opposition; elastic properties in low carbon steel (Koralnik *et al*., 2020). It apparently helps the grip of paint. At the point when Cu and other alloying components are included their fitting amounts, with appropriately controlled microstructure, quality steel is delivered. The significant issues with steel production currently are the crude materials, which are the reuse scraps (Stephen *et al*., 2014).

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Method of the Study

The mechanical failure analyses of reinforced steels were analyzed in accommodating the hardness, microstructure variations, tensile and yield strengths in collapsed buildings. The analysis combination then be presented using mathematical and graphical expressions, to generate results with the equations, to reveal the effects of steel failure during the period of collapsed in the due course of researching such as; data for the experiment being collected from Ahmadu Bello University (ABU), Zaria for tensile and hardness tests, and National Steel Raw Materials Exploration Agency

(NSRMEA), Kaduna for Scanning electron microscope (SEM) and Energy dispersive X-ray spectroscope (EDS) and it will be compared to the experimental data base of the chemical composition of mild steel.

The results will then predict the yield strength distribution in reinforced steel of 12 millimeter (mm) diameter in the course of collapsed buildings. Several experimental results of tensile strength have been used to study the yield strength of reinforced steels which quantified the major parameters related to their failure resistance. A mathematical expression for sampled of each specimen was examined separately with almost 12 different building collapse sites in Nigeria keeping all required parameters in rigorous checking in each case. The research results make possible a better examination of the effect of tensile strength, yield strength, hardness and microstructure on the reinforced steels used in building and structural construction in Nigeria.

3.2 Sample Size and Sampling Procedure

Specimen of the Reinforced Steels were collected from the sites of collapsed buildings in each cities of Lagos, Abuja, Ibadan, Port Harcourt, Uyo, Jos, Edo and Kano, all together numbering up to 36 specimens. In each sites, samples of steel rods in a considerable length of 12 mm diameters were collected.

Moreover, each of the specimens examined separately for hardness test conducted on BROOKS INSPECTION EQUIPMENT testing machine of serial number 070727A with upper limit of 600 at ABU, Zaria. Also, microstructure examinations result from the Scanning Electron Microscope (SEM) and Energy Dispersive X-ray Spectroscope (EDS) machine of the specification attached FOV: 537 µm, Mode: 15 kV - Image, Detector: BSD Full at NSRMEA, Kaduna, keeping all required parameters constant recorded in each case.

3.3 Tensile Strength Test

Tensile Strength predicts the ability of a material to withstand forces that pulls it apart as well as the capacity of such to stretch before the point of failure (Ibrahim *et al*., 2013). Based on this fact, the tests on reinforced steels gotten from the collapsed buildings were conducted by using this strength of material method approach as presented in Figure 3.1.

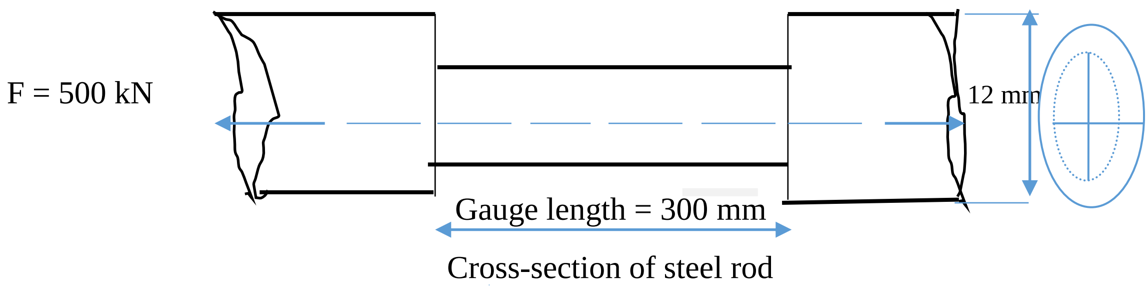

Figure 3.1: Standard sampled steel for tensile test with gauge length of 300 mm and diameter of 12 mm

The tensile tests were carried out according to British standard BS: DENISON® standard calibrated in Kilonewton (kN). An average maximum load (kN), yield load (kN) and the breaking load (kN) were displayed on the analogue meter gauge of the 500 kN capacity machine, and these values were recorded. The test was repeated on each samples diameter from different locations for the period of three times. The average tensile strength (N/mm^2) was determined and finally average yield strength (N/mm^2) for each samples of different diameters from different locations were determined, by the equations: (1) and (2).

$$\sigma = \frac{P_u}{A_o} \qquad (N/mm^2) \qquad (1)$$

$$\delta = \frac{F_u}{A_o} \qquad (N/mm^2) \qquad (2)$$

where σ: is the average tensile strength of the samples, in (N/mm^2).

δ: is the average yield strength of the samples, in (N/mm^2).

F_u: is the applied yield load on the samples, in Newton (N).

P_u: is the applied breaking load on the samples, in Newton (N).

A_o: is the instantaneous cross sectional area of the test piece samples, in mm^2.

3.4 Microstructure Analysis

Metallographic tests were cut from supported steel tests of imploded fabricating destinations to control sizes. For the investigation interaction, examples were cleaned utilizing belt polisher and later by emery papers of different framework sizes, for example, 600, 800 and 1200 individually. Exhaustively, velvet fabric cleaning was utilized with alumina slurry and jewel glue. Metallographic pictures were produced using the FOV: 537 µm, Mode: 15 kV - Image, Detector: BSD Full machine, utilizing computer coordinated and the circulations of particles were noticed and recorded by examining electron magnifying instrument (SEM) and Energy Dispersive X-beam Spectroscope (EDS).

3.5 Hardness Test

A point on contact of hardness testing machine was utilized to examine the hardness conduct according to NIS 117 (0.350 wt. % C), BS4449 (0.250 wt. % C) and ASTM (0.300 wt. % C) norms at consistent climatic conditions. Contact surfaces were ready by grating them against silicon carbide paper and $(CH_3)_2CO$ were utilized to clean the circle and kept in touch region between the point and the example surface region and protected the cycles with the consistent expulsion of garbage, consistency of surface conditions, simple hardness estimation and simple read of results. The example of built up steel point with a hardness of 12 mm width and 10 mm tallness of tests were utilized for testing. Three resources on each example were utilized as partner of hardness. During the test, the fact of the matter was squeezed against the example surface with variable heaps of 122 N. The example was fixed and care has been taken so that cross part of the example was in touch with the plate during the analysis. Toward the finish of each test, the plate was cleaned and its end-product was recorded.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Tensile Test and Yield Strength Analysis

The data used in this research work is from the laboratory results which predict the yield strength (N/mm^2) on each samples of 12 mm diameter from different 12 locations of collapsed building. In this research, a reference codes of BS4449:1997 as 460 N/mm^2 (Ede *et al.*, 2015), and (Kareem, 2009), NIS117 as 420 N/mm^2 and ASTM as 415 N/mm^2 (Odusote *et al.*, 2019) were used as a standard for the yield strength measured in N/mm^2. These are the only referred to as a bench mark parameters to justify the failure of reinforced steel materials that collected from the collapsed building sites in Nigeria without any hitches. Any Laboratory test results that act contrary to this standard of yield strength in N/mm^2 is considered to be a failed material with the characteristic of low or high yield strength irrespective of samples diameter. The result is reported below in Table 4.1 and presented in Figure 4.1.

Table 4.1: Yield strength of 12 mm diameter for the Reinforced Steel

S/N	Location	Average Tensile strength (N/mm^2)	Average Yield Strength (N/mm^2)	Average Percentage Elongation (%)	Remarks
1.	ABJ 01	509.06	357.43	14.22	Failed
2.	ABJ 02	431.01	390.30	13.76	Failed
3.	EDO	591.53	368.24	13.40	Failed
4.	IBD	525.97	397.31	12.10	Failed
5.	JOS	459.16	364.58	12.30	Failed
6.	KAN	430.81	402.18	14.80	Failed
7.	LAG 01	556.74	374.74	13.33	Failed
8.	LAG 02	480.05	405.13	13.67	Failed
9.	LAG 03	572.51	318.95	13.13	Failed
10.	LAG 04	509.14	369.11	14.17	Failed
11.	PHC	427.37	367.05	12.13	Failed
12.	UYO	559.63	326.87	12.44	Failed
13.	NIS117	485.40	420.00	14.00	Control
14.	BS4449	677.20	460.00	14.00	Control
15.	ASTM	480.00	415.00	14.00	Control

The Table 4.1 above showed that the results generated according to the relevant theory applied and through the experiment performed have attributed the yield strength values range from 318.95 to 405.13 (N/mm^2) of all the reinforced steel samples were characterized with structural failure even with all the parameters concerned as against the NIS117 code of 420 N/mm^2, BS4449:1997 code of 460 N/mm^2 and ASTM code of 415 N/mm^2. Therefore, the results are in negative agreement with all the standard codes, and 100 % failed data specification.

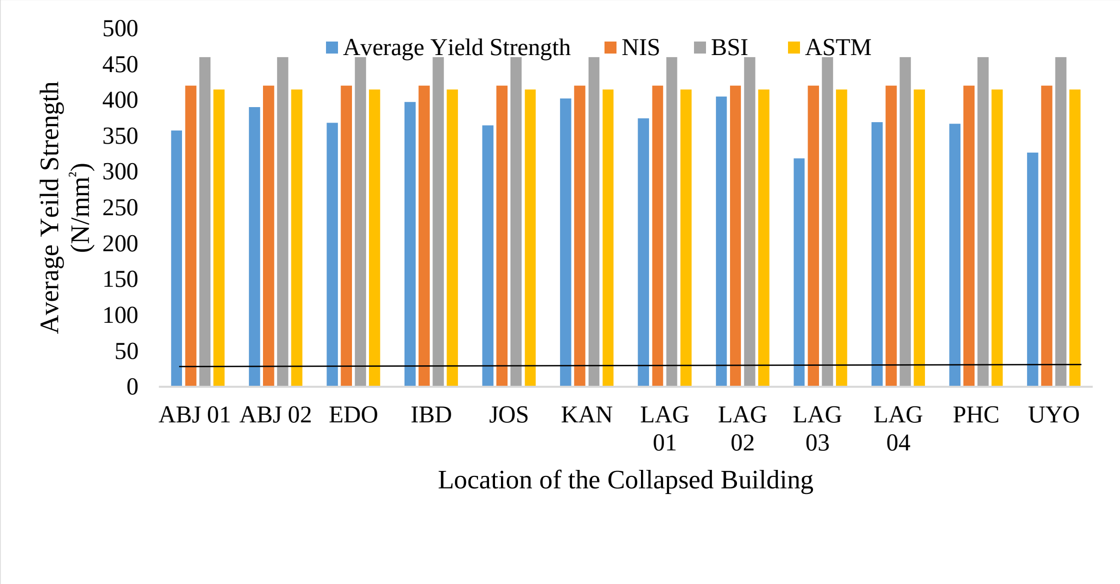

Figure 4.1: Average Yield Strength against the Standards for the Reinforced Steel

The average yield strength observed for all the 12 collapsed building locations as indicated in Figure 4.1 were not in points with the standard. This showed that the sampled steels were failed. This could be proved that the use of these mild steels in respective of dimensions as composites reinforcement into cement will probably generate greater building and other structural failure as being shown above. It is possible to note the presence of variations in the yield strength which characterize the material behaviour. Meanwhile, the validation procedure could be in studying the effect of hardness and microstructure examination of reinforced mild steel in comparison to yield strength analysis as presented in subsequent test analyses.

4.2 Hardness Test Analysis by EDS

Hardness test results on reinforced steel samples of 12mm diameter from 12 different locations of collapsed building across Nigeria by EDS are presented against the hardness behaviour standard as measured according to NIS117 (0.350 wt. %), BS4449 (0.250 wt. %) and ASTM (0.300 wt. %) standards at constant atmospheric conditions (NIS, 1992).

Table 4.2: Hardness Test Results by EDS

S/N	Location	Hardness value (HV. %)	Remaks
1	ABJ 01	0.160	Below
2	ABJ 02	0.180	Below
3	EDO	0.230	Below
4	IBD	0.210	Below
5	JOS	0.230	Below
6	KAN	0.230	Below
7	LAG 01	0.140	Below
8	LAG 02	0.190	Below
9	LAG 03	0.240	Below
10	LAG 04	0.160	Below
11	PHC	0.180	Below
12	UYO	0.220	Below
13	NIS117	0.350	Standard
14	BS4449	0.250	Standard
15	ASTM	0.300	Standard

From the results presented in Table 4.2, the hardness test values by EDS shows that the distribution of hardness of the sampled materials made of the steel ranged from 0.14 wt. % to 0.24 wt %, for the sited collapsed buildings. It can be deduced from the analysis of the results that all the hardness values of the 12 sampled steel such as ABJ01, ABJ02, EDO, IBD, KAN, JOS, LAG01, LAG02, LAG03, LAG04, PHC, and UYO were all below the standards considered. The hardness of the steel is absurd, one revealed the areas of a higher (0.24 wt %) not reaching 0.25 wt %, which is a prerequisite for the minimum standard application of the steel according to BS4449:1997. The analysis of the above hardness tests can thus be presented thus;

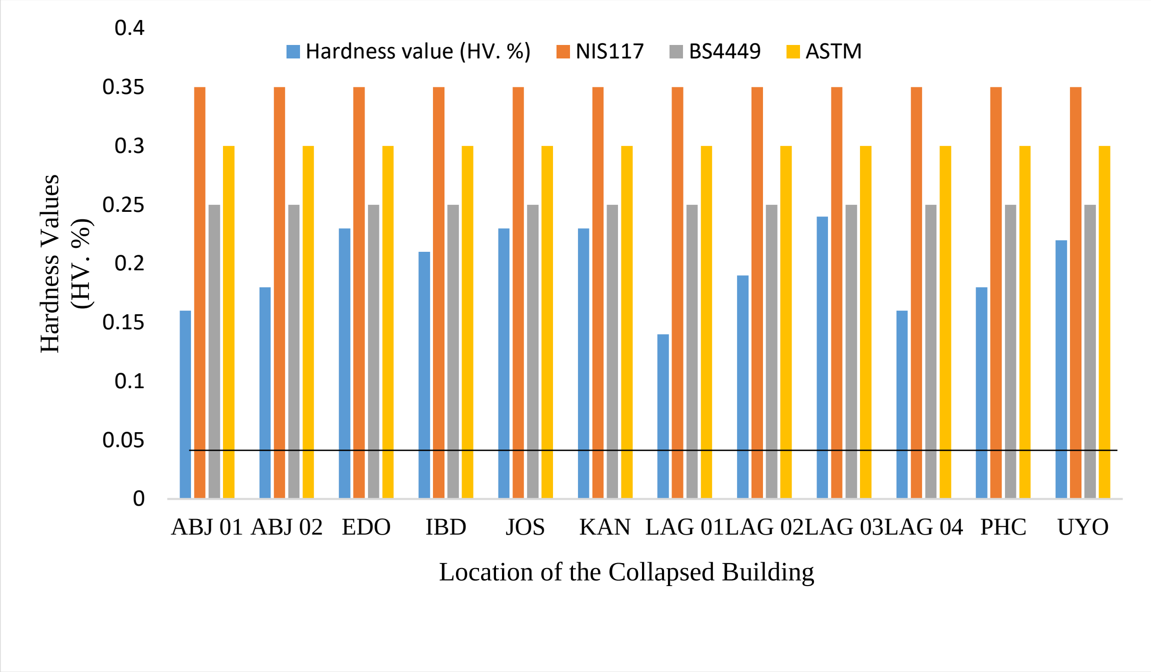

Figure 4.2: Hardness Values versus the Standards for the Reinforced Steel

However, from the Figure 4.2, the ramifications of the hardness test for this situation could not measure up to others in which the sample is completely fizzled. In any case, the way that a sample is not totally satisfied the guideline code does not disparages the standard codes. This conduct verifies the burst system of breaks that spread specially in the middle of the compaction of the steel synthesis because of the low interfacial strength. The more prominent break region will be identified with the lower or higher carbon weight fixation (wt. % C), legitimize the underlying disappointment of the inspected steel.

4.3 Microstructure (Metallographic) Analysis

Microstructure assessment is needed to distinguish the particular components and arrangements associated with the creation interaction of steel. The microstructure investigations of the supported sample steels from various 12 fell locales across Nigeria were then controlled by the SEM-EDS assessment. This method estimated the substance of the components with great reproducibility, quick test speed and high affectability. The stage arrangements of the basic segments were likewise procured and the morphology of the sample was inspected while the molecule size conveyance of the not set in stone utilizing an analyzer with the pictures at explicit amplifications as displayed in the Table 4.3.

4.4 Discussions of Microstructure Examinations

The microstructures of the sampled steels revealed an unequalled grain configuration with extreme presence of sulphur (S), phosphorous (P), and oxygen (O) as presented in the discussion of metallographic images. The whitish colour reveals the matrix of ferrite, the dark colour indicates the pearlite while the (black) indicates the carbon chromate that was created due to the existence of disproportionate oxygen. Each plate represented each sample steel from the 12 locales and was denoted as Plate I – XII. It also reveals from each plate the steel that has undergone weariness abnormality which is created by fatigue variation for a long duration and eventually cracked due to the fact of disproportionate oxygen. The research proved to be the very abnormal properties of steel products. Hence, the existence of the elemental composition of Titanium (Ti), Chromium (Cr), Tin (Sn), and chemical composition of Aluminium (Al), and Silver (Ag) at an increased weight percent (wt. %) concentrations may be hastened construction and other structural building collapses.

Table 4.3: Elemental composition of reinforced steel results

S/N	Location	Elemental compositions (weight concentration) in percent (%)																
		Fe	C	S	P	Si	Na	Ca	K	Al	Ag	O	Mn	Sn	Ti	Cr	V	Cl
1.	ABJ 01	85.2	0.14	0.75	0.62	0.80	0.67	0.61	0.82	0.48	1.27	5.31	-	0.82	0.51	0.52	0.31	1.26
2.	ABJ 02	81.9	0.16	0.68	0.39	1.24	1.09	0.73	1.54	0.70	1.40	6.02	-	1.23	0.39	-	-	2.53
3.	EDO	82.5	0.25	0.65	0.71	0.91	2.58	0.87	2.62	0.42	1.74	5.37	-	1.13	0.25	-	-	-
4.	IBD	79.3	0.19	0.86	0.62	1.14	3.02	1.06	2.32	0.77	1.76	5.11	-	2.04	0.66	0.57	0.58	-
5.	JOS	81.7	0.37	0.51	0.44	1.02	1.58	0.63	0.97	0.13	1.25	6.12	-	1.37	0.50	0.89	0.46	2.06
6.	KAN	86.0	0.38	0.52	0.42	1.14	3.00	1.08	2.20	0.07	0.06	5.11	-	0.02	-	-	-	-
7.	LAG 01	82.7	0.38	0.69	0.50	2.36	2.49	0.72	2.82	0.01	0.74	6.48	-	0.03	0.08	-	-	-
8.	LAG 02	84.1	0.34	0.04	0.03	0.91	2.36	0.08	2.82	0.42	1.74	5.78	0.22	-	0.41	0.75	-	-
9.	LAG 03	88.0	0.35	0.03	0.01	1.01	2.75	0.66	1.22	0.42	1.30	4.25	-	-	-	-	-	-
10.	LAG 04	86.5	0.51	0.73	0.51	0.46	1.03	0.86	1.86	0.32	1.26	4.60	1.36	-	-	-	-	-
11.	PHC	81.5	0.45	0.70	0.65	2.58	2.96	3.41	0.88	0.28	0.26	5.61	0.72	-	-	-	-	-
12.	UYO	87.2	0.42	0.03	0.13	0.37	2.57	0.86	2.58	0.22	0.51	4.31	0.80	-	-	-	-	-
13.	CONTROL	BAL	0.30	0.03	0.03	0.21	-	-	-	0.01	-	-	0.6	0.03	0.01	0.15	0.02	-

4.5 Discussions of each Microstructure Image

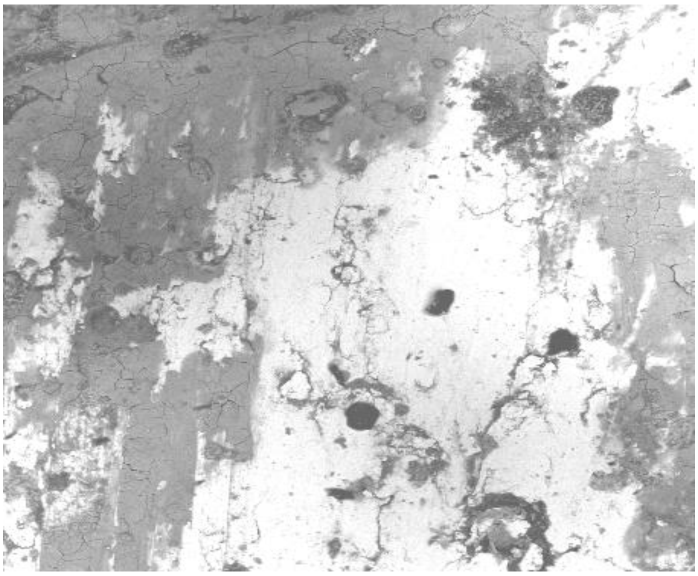

Plate I: Metallographic Image of ABJ 01

The microstructure reveals unequaxed grain structure with excessive sulphur (0.75 wt. %) and phosphorous (0.62 wt. %). The (whitish) colour indicates the matrix of ferrite, the (dark) colour indicates the pearlite while the (black) indicates the carbon chromate that formed due to the presence of excessive oxygen (5.31 wt. %). It also reveals the steel that undergone fatigue aberration which initiated from fatigue striation for a long period time and finally fractured due to the presence excessive oxygen. The analysis proved very abnormal properties of steel product. Hence, the presence of elemental composition of Titanium (Ti), Chromium (Cr), Tin (Sn), and chemical composition of Aluminium (Al), and Silver (Ag) at a high weight percent (wt. %) concentrations may haste building collapse.

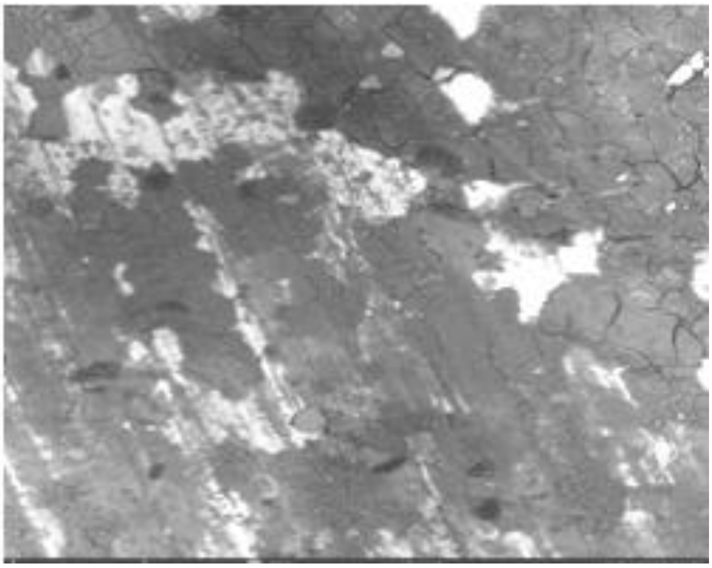

Plate II: Metallographic Image of ABJ 02

This microstructure examination reveals similar properties as ABJ 01. It shows a structure that undergone fatigue aberration for a long period of time which eventually leads to a fatigue failure. It shows iron cementite (FeC_3) (dark) with formation of iron oxide due to the excessive formation of oxygen in the matrix of ferrite (white). With the presence of excessive sulphur (0.68 wt. %) and phosphorous (0.39 wt. %), iron sulphite ($FeSO_3$) (black) was formed which was the areas of severe corrosion in the steel, in the matrix of ferrite. This is also very abnormal in the steel product of structural steel products. The crack present in the steel structure may be rapid in the process as a result of presence of elemental composition of Titanium (Ti), and chemical composition of Aluminium (Al), and Silver (Ag) which were included at a high weight percent (wt. %) concentrations.

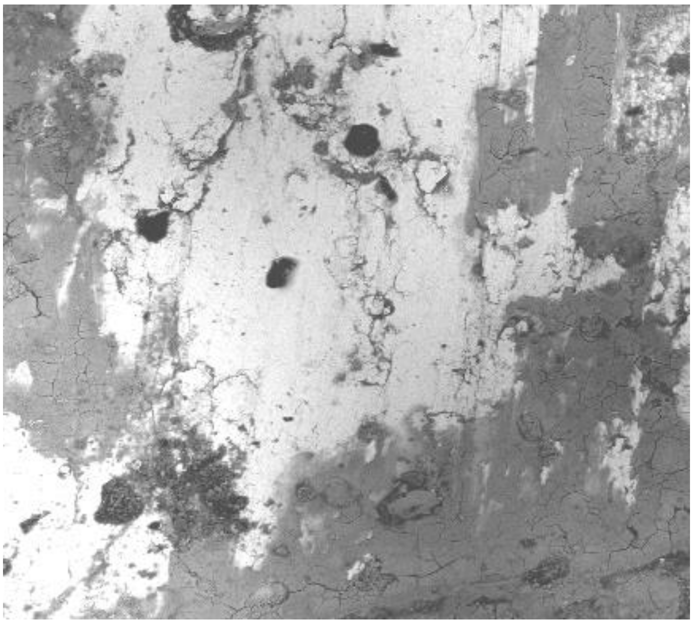

Plate III: Metallographic Image of Edo

The microstructure analysis reveals similar characteristics to the ABJ01 and ABJ02 above. Poor structure that it is obviously indicates a steel that undergone a fatigue striation to fatigue aberration before finally ended up in a fatigue failure due to the excessive presence of sulphur (0.65 wt. %), phosphorous (0.71 wt. %) and oxygen (5.37 wt. %). Due to the presence of high oxygen, the formation of iron sulphite ($FeSO_3$) (black) attributes severe corrosion in the steel in the aggregate matrix of ferrite. It can be proved from the analysis that the product is due to fail, with absurd mechanical properties. The abnormal presence of elemental composition of Titanium (Ti), and chemical composition such as Aluminium (Al), and Silver (Ag) included at a high weight percent (wt. %) concentrations, may speed up to structural failure.

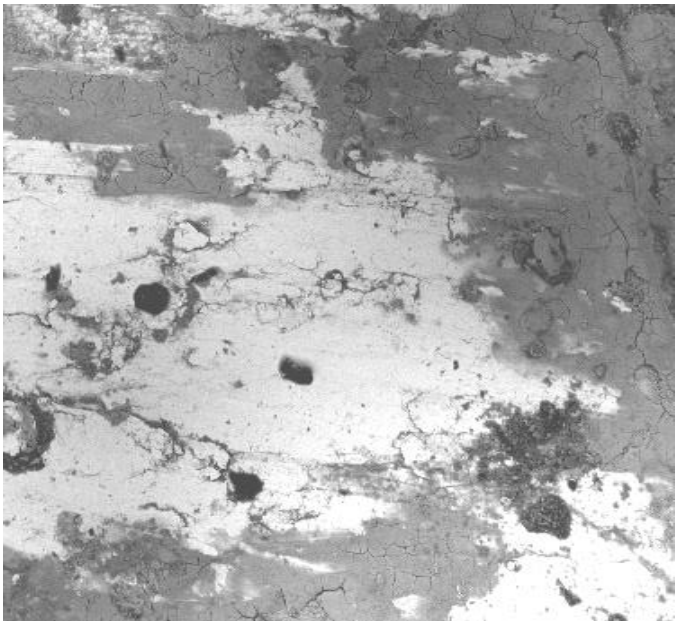

Plate IV: Metallographic Image of IBD

It can be induced from the microstructure the similarities in properties as ABJ01, ABJ02 and EDO, the iron sulphite ($FeSO_3$) (black) that present due to the presence of excessive oxygen (5.11 wt. %), sulphur (0.86 wt. %) and phosphorous (0.62 wt. %) also lead to the corroded areas (black) in the structure. The presence of iron (79.32 wt. %) indicates as the main element. The content reveals too much of pearlite (black) thereby causing formation of ferrite (white) by the presence of Iron-Sulphite ($FeSO_3$). Due to the high content of phosphorus and sulphur as much as oxygen, it can then be categorized as a precipitation of Iron-Sulphite ($FeSO_3$). The formation of Iron-Sulphite will eventually make the steel to melt, even at a lower temperature thereby lead to crack and subjected to be too brittle and thereby causes 'red and cold shortness'. And finally leads to failure (fracture) in the steel. The reason for this is as a result of poor production through the steel's abysmal performance, which is due to the severe distortion of the microstructure occasioned by the development of incoherent complex compounds. It is concluded that the presence of Iron-Sulphite is deleterious to structural steel performance and usually cause building collapse.

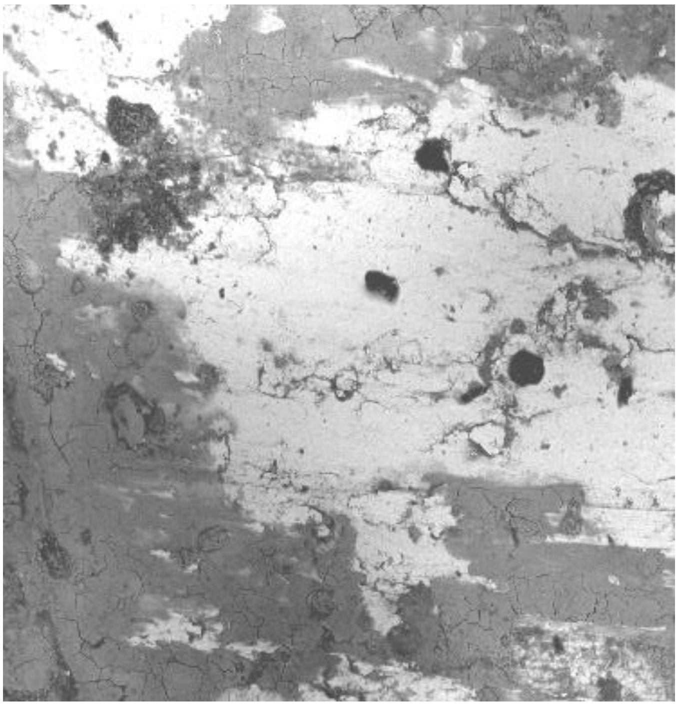

Plate V: Metallographic Image of JOS

The microstructure shows the chemical composition in which iron (81.72 wt. %) as the main element as in relation to the aforementioned analyses of ABJ01, ABJ02, EDO and IBD. The aggregate content contains coarse grain structure with high weight percent of sulphur (0.51 wt. %), oxygen (6.12 wt. %) and phosphorus (0.41 wt. %). With these compositions, it indicates the level of pearlite (black) in the matrix of ferrite (white). Formation of Iron-sulphite is also severe, which may lead to steel fracture at any time in service. This confirmed the structural failure under certain metallurgical conditions, causing separation of phases which weaken the pearlite reinforcing phase.

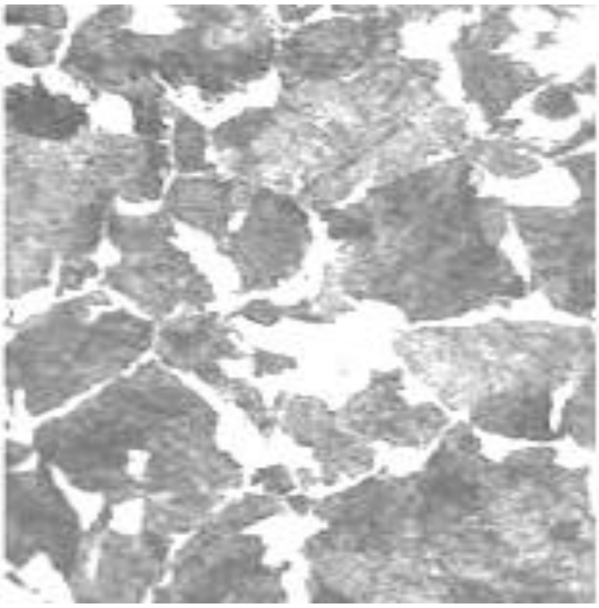

Plate VI: Metallographic Image of KAN:

The steel shows fine and good equaxed grain structure but it appears with dimples grains that so much be taken over by a dominated iron sulphite ($FeSO_3$) (black). This present due to the excess oxygen concentration lead to the corroded areas (black) in the structure. The microstructure reveals the chemical composition in which Iron (85.98 wt. %) as the main element, but the content reveals a severe phosphorus (0.42 wt. %) and sulphur (0.52 wt. %) as much as carbon (0.38 wt. %). Thereby makes the steel to be brittle which may make it experience fatigue aberration easily at a constant loading, thereby causing unexpected failure in practice. The illustration from the microstructure also indicates the presence of the two particle size of coarse grain structure as pearlite (black) in the matrix of ferrite (white). This is very abnormal in the steel product of structural steel products.

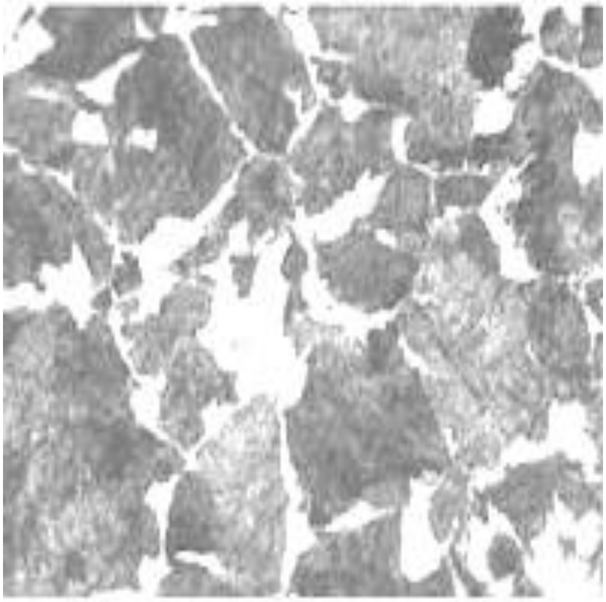

Plate VII: Metallographic Image of LAG 01

The microstructure reveals the composition very similar to KAN as analysis above, except it shows a structure that contains the excessive formation of carbon chromate (dark) at the grain boundary. It also reveals severe corroded areas (black) due to the excessive formation of oxygen content. It contains a severe phosphorus (0.50 wt. %), sulphur (0.69 wt. %) and carbon (0.38 wt. %) contents, thereby making the steel to be brittle. The steel lack of mechanical property termed ‘ductility’, thereby cannot withstand the load applied for a long period of time. However, it is a product of failed steel.

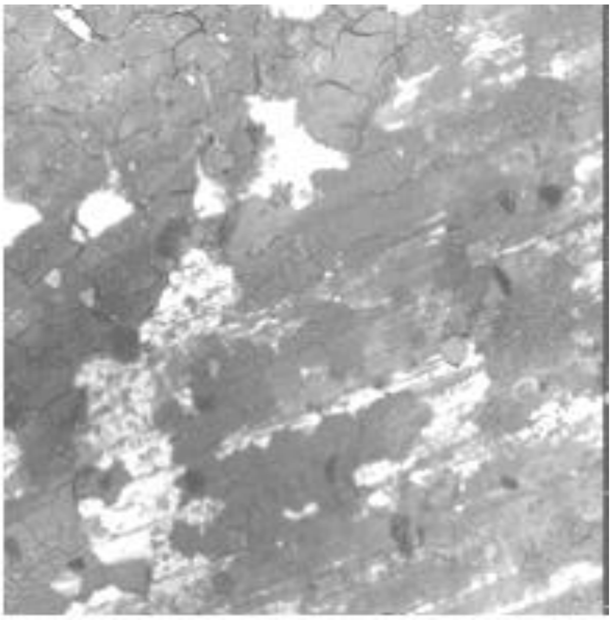

Plate VIII: Metallographic Image of LAG 02

The steel reveals poor formation of structures that shows an obvious deformation and failure which leads to unequaxed grain structure which contains pearlite (dark) like tiny thread structure embedded with cementite (FeC_3) (gray), in the matrix of ferrite. The sampled steel appears as steel that does not undergo a complete production process due to the presence of bainite (feather-like) structure that appeared in the microstructure. The structure shows the mechanical properties, that liable to be brittle which may make it experience fatigue aberration easily at a constant loading, thereby causing unexpected failure in building and other structural facilities. From the analysis above, it can be easily confirmed as a very abnormal practice in the production of steels for building and other construction amenities.

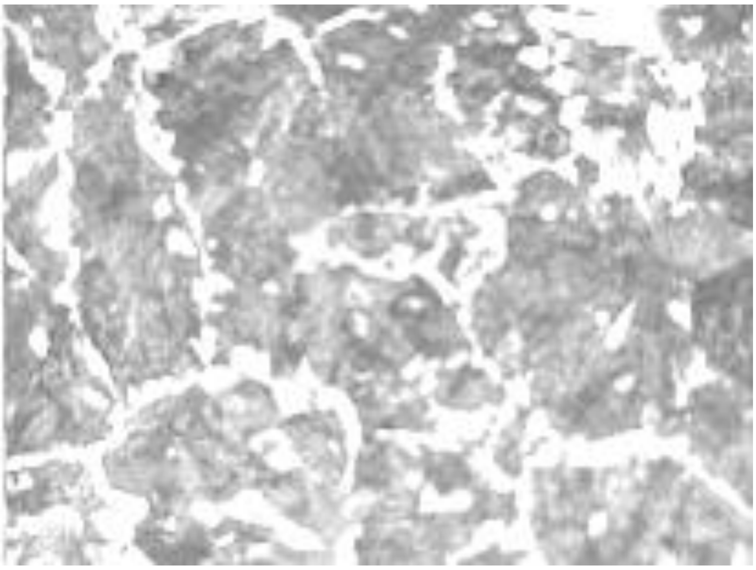

Plate IX: Metallographic Image of LAG 03

The microstructure reveals a steel that totally taken over by the formation of iron cementite (FeC_3) (dark) leaving the narrow or tiny structure of ferrite (white) at the grain boundaries. It also shows corroded areas (black) due to the excessive formation of oxygen in the structure. The above microstructure shows that the sampled steel is characterized by high content of iron and carbon (0.35 wt. %). Due to the formation of iron-sulphite in the process, it is anticipated that the steel is very brittle and may cause building collapse within a very short life span. This can be easily deduced as characterized the structural failure under mechanical and metallurgical conditions.

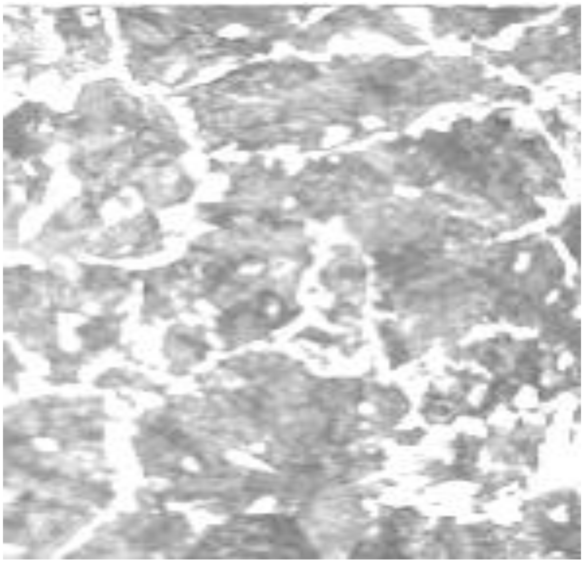

Plate X: Metallographic Image of Lagos 04

The microstructure reveals a severe brittleness due to excessive formation of sulphur and phosphorous. Iron sulphite ($FeSO_3$) (black) has totally dominated all the region of the microstructure due to excessive presence of oxygen, leaving only few or scanty ferrite (white) in a small domain across the region of the microstructure. The ugly presence of Phosphorus (0.51 wt. %), sulphur (0.73 wt. %) and oxygen (4.60 wt. %) concentration were also in excess which led to the brittleness of the steel. Thereby, it may lead to fracture. It can be categorized as a steel of structural failure under certain metallurgical conditions, causing separation of phases which weaken the pearlite reinforcing phase.

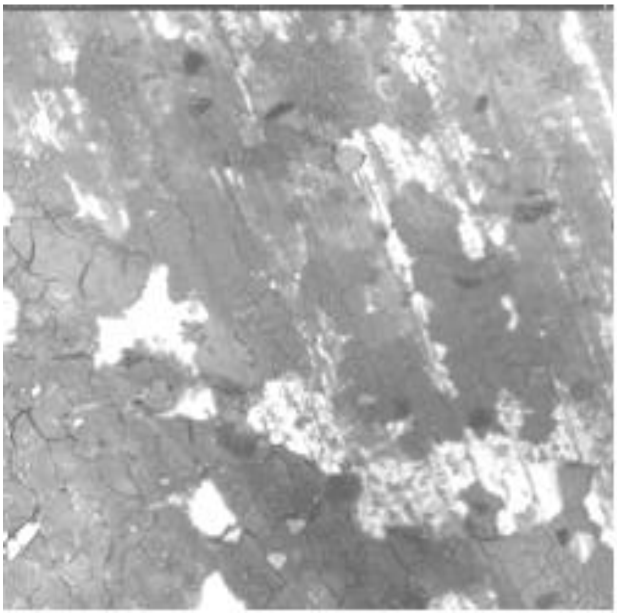

Plate XI: Metallographic Image of PHC

This microstructure reveals the same properties as that of LAG 02 above, except it shows more or severe formation of iron cementite (dark) but with more presence of ferrite interwoven in its matrix which characterized by dimples and damping structures that passes through a fatigue failure under a severe load. The phase composition of the analysis indicates the formation of Cementite (FeC_3, dark) embedded with pearlite (black) in the matrix of ferrite (white). There is also high degree of phosphorus (0.65 wt. %), sulphur (0.70 wt. %) and carbon (0.45 wt. %) in terms of weight concentration. It is seen that there exist three hazardous elements for the easy structural failure. It can also be deduced from the microstructure analysis that the sampled steel was produced at abnormal lower temperature of about 800 ˚C without proper homogenization. From the microstructure analysis, it proved the structural failure under different variation of mechanical and metallurgical conditions.

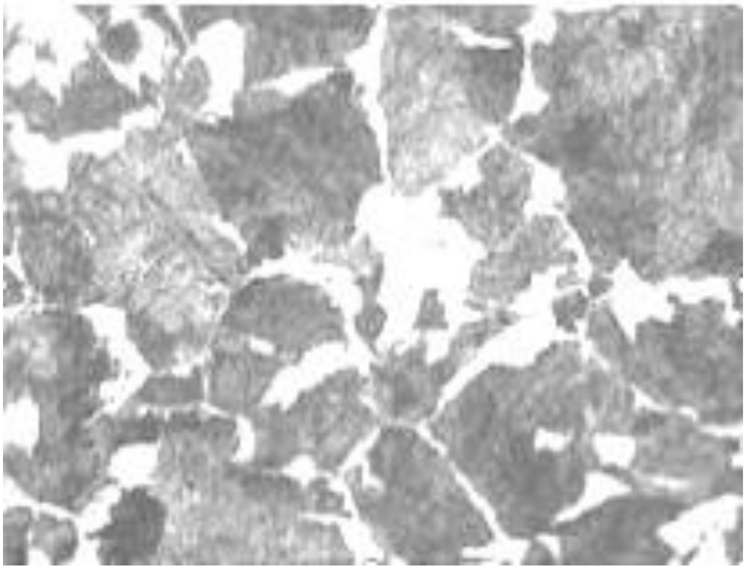

Plate XII: Metallographic Image of UYO

The microstructure reveals a steel that possess similar properties as that of LAG03, which totally taken over by the formation of iron cementite (FeC_3) (dark) leaving the narrow or tiny structure of ferrite (white) at the grain boundaries. It also shows corroded areas (black) due to the excessive formation of oxygen in the structure. The microstructure revelation of ferrite (white) light structure with (dark) stripes within the light (white) structure and as well as pearlite (black) in a small quality in the matrix of ferrite (white), were due to the presence of high degree of carbon (0.42 wt. %). It can also be deduced from the microstructure analysis that the sampled steel was produced at abnormal lower temperature of about 800 ˚C without proper homogenization. It can then be confirmed from the microstructure analysis as the structural failure under variation of mechanical and metallurgical conditions due to the poor pearlite reinforcing phase.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Having carried out the failure analysis of steel reinforcement in collapsed buildings in Nigeria, the following are the conclusion drawn accordingly;

From the result of tensile and yield strength, 100 % of the steel reinforcement used for building construction in all the visited collapsed building sites failed woefully the tensile and yield strength tests. The implication of this is that, the building designers did not use quality steel reinforcement that could have met the BS 4449:1997 code of 460 N/mm^2.

Secondly, the results of the hardness reveals that none of the reinforced steel bars samples gotten from sites of collapsed building met the British Standard (BS 4449:1997) of 0.25 (wt. %). The implication of this is such that, virtually all the steel reinforcement are too brittle as none of it were up to 0.25 (wt. %). As a result of this, they were very prone to/ tensile failure when subjected to a fatigue load in application.

Thirdly, the result of the microstructure reveals poor elemental and chemical compositions of steel which were characterized by low carbon, excessive sulphur and phosphorus contents that are not vibrant enough to carry an applied load for a very long time.

5.2 Recommendations

This thesis will serve as a basis for further research into reinforced steel bars and related building collapse, especially in Nigeria. Government should consider it as a duty to inspect and carry out evaluation test on the properties of steel bars produced by steel manufacturing companies in Nigeria from time to time to ascertain the standard required in term of mechanical properties for the steel. Also, to enforce the necessary laws attached before any product can be used for the purpose of construction. This tends to avoid the calamity imposed that may occur due to unnecessary negligence and inconsistency. Moreover, all and each construction companies should be compelled to build standard and equipped laboratory for all the necessary tests and documented the analysis certificates for national purposes and development.

5.3 Contribution to the Knowledge

The thesis work proffers area of solution to the problem of building collapses through the necessary strength tests analysis carried out on steels used in building construction in Nigeria which showed that 100 % of reinforced steel from all collapsed building sites visited failed the standard tests. It also serves as a guide for the policy makers to create suitable policies that will help and improve the existence of the indigenous steel manufacturers since the research evaluated the presence of high weight percent (wt. %) concentration of carbon (0.51 %), phosphorus (0.71 %), sulphur (0.86 %) and oxygen (6.48 %) which proved brittle nature of the steels. The course of this research project will serve as encouragement to all stakeholders in building construction to take caution of the standard of the steel reinforcement to be used for the building construction in Nigeria.

REFERENCE

Adebowale, P. A., Gambo, M. D., Ankeli, I. A. & Daniel I. D. (2016). Building Collapse in Nigeria: Issues and Challenges. *International Journal of Arts and Sciences conference*, 9(1), 99-108.

Adeniregun, A. O. (2010). Study of Building Collapse In Nigeria: Effects of Poor Construction Materials and Poor Workmanship: A Student Project, Department of Civil Engineering, Covenant University, Ota, Nigeria.

Adetoro, A. E. & Oladapo, A. S. (2017). Assessment of Suitability of Selected Reinforcing Bars Used for Construction in Nigeria. https//www. semanticscholar.org

Adzora, S. A., Nnukab, E. E. & Nnakwob, K. C. (2019). Effect of Welding Consumableson the Mechanical Properties of Micro-Alloyed Steel Weldment. *International Journal of Innovative Science and Research Technology*, 4(6), 419-425.

Akande, B. F., Debo-Saiye, B., Akinjobi, S. D., Alao, T. O. & Akinrogunde, O. O. (2016). Causes, Effects and Remedies to the incessant Building collapses in Lagos state, Nigeria. *International Journal of Basic and Applied Sciences,* 16(04).

Alamu, O. J. & Aiyedun, P. O. (2003). A Comparison of Temperature Gradient in Hot Rolling at Low and High Strain Rates. *.Journal of Science and Engineering Technology*, 10, 44-54.

Alaneme, K. K., Fajemisin, A. V. & Maledi, B. N. (2019). Development of Aluminum-based composite reinforced with steel and graphite particles, Structural, Mechanical and Wear characterization, *Journal of material research and technology,* 8(1), 670-682.

Almarwae, M. O. (2017). Structural Failure of Buildings: Issues and Challenges. *The Scientific World Journal*, 66, 97-108.

American Society of Testing and Materials (2001). Standard Specification for Low-Alloy Steel deformed and Plain Bars for Comcrete Reinforcement, *American Society of Testing and Materials,*ASTM706, Philadephia.

British Standard (1997). Specification for the Carbon Steel Bars for the Reinforcement of Concrete. *British Standard*, BS4449:1997, May 15.

Bukola, A. (2010). Nine feared dead in Abuja building collapse. http://thenationonlineng.net/news

Callister, D. W. (2007). The iron – iron carbon phase diagram. *Materials Science and Engineering / An Introduction*". 7th edition, John Wily and Sons Inc, New York.

Chandrashekar, S., Trease, N. M., Chang, H. J., Du, L. S., Grey, C. P. & Jerschow, A. (2012). 7 Li MRI of Li batteries reveals location of microstructural lithium. *Journal of Nature materials*, 11(4), 311.

Chendo, I. G. & Obi, N. I. (2015). Building collapses in Nigeria. The causes, effects, consequences and remedies. *International Journal of Civil Engineering, Construction and Estate Management*, 3(4), 41 – 49.

Ede, A. N. (2010 a). Building collapse in Nigeria: The trend of casualties in the Last Decade (2000-2010). *International Journal of Civil and Environmental Engineering*, 10(6). 31- 42.

Ede, A. N. (2010 b). Structural Stability in Nigeria and Worsening Environmental Disorder: the Way Forward. *Proceedings of the West Africa Built Environment Research Conference, Accra, Ghana, July 26-28*, 2010. 489-498.

Ede, A. N., Egunjobi, E. O., Bamigboye, G. O. & Ogundeji, J. (2015). Assessment of Quality of steel Reinforcing Bars used in Lagos, Nigeria. *International Research Journal of Innovative Engineering*, 1(6), 31-42.

Figiel, P., Biedunkiewicz, A., Biedunkiewicz, W., Grzesiak, D. & Pawlyta, M. (2020). Corrosion Characteristics of Composites of (Mo,Ti)C/Ti and TiC/Ti Type Manufactured with SLM Technique. *Archives of Metallurgy and Materials*, 60(1), 56-61.

Gowda, S., Manigandan, K., Patnaika, A. & Srivatsan, T. S. (2017). Influence of Exposure to an Aggressive Environment onCyclic Fatigue Response and Life of an Alloy Steel. *The Journal of Engineering*, 14(2), 124-136.

Hamma, A. & Koulder, T. (2017). Causes of Building Failure and Collapse in Nigeria: Professional view. *American Journal of Engineering Research*. 6(12), 289–300.

Kareem, B. (2009). Tensile and Chemical Analyses of Selected Steel Bars produced in Nigeria. *Assumption University Journal of Technology,* 13(1), 29-33.

Kingsley, O. D. (2010). Incessant Incident of Building Collapse in Nigeria. A challenge to stakeholders. *Global Journal of Researches in Engineering*, 10(4), 75.

Klaput, J. (2015). Application of small punch test method in studies of the 14MoV63 steel before and after revitalization. *Archives of Metallurgy and Materials*, 60(1), 62-69.

Koralnik, M., Dobkowska, A., Adamczyk-Cieslak, B. & Mizer,a J. (2020). The Influence of the Microstructural Evolutin on the Corrosion Resistance of Cold Drawn Copper Single Crystal in NaCl. *Archives Metallurgy and Materials*, 65(1), 55-64.

Kulka, M., Makuch, N., Pertek, A. & Piasecki, A. (2012). Microstructure and properties of borocarburized and laser-modified 17CrNi6-6 steel. *International Journal of Optics and Laser Technology*, 44, 872–881.

Lukaszcyk, A. & Augustyn-Pieniazek, J. (2015). Corrosion resistance of co-Cr-Mo Alloy used in Dentistry. *Archives of Metallurgy and Materials*, 60(1), 32-39.

Millogo, Y., Morel, J. C., Traoré, K. & Ouedraogo, R. (2012). Microstructure, geotechnical and mechanical characteristics of quicklime-lateritic gravels mixtures used in road construction. *Construction and Building Materials*, 26(1), 663-669.

Mouhyi, J., DohanEhrenfest, D. M. & Albrektsson, T. (2012). The peri-implantitis: implant surfaces, microstructure, and physicochemical aspects. *Clinical implant dentistry and related research*, 14(2), 170-183.

Nigerian Building and Road Research Institute (2011). *Proceedings of the Stakeholders forum, May 2011*. Nigerian Building and Road Research Institute.

Nigerian Institute of Steel (1992). Specification for Steel Bars for Reinforce- ment of Concrete. *Nigerian Institute of Steel*, NIS 117.

Nwachukwu, P. U. & Oluwole, O. O. (2016). Case study Effects of rolling process parameters on the mechanical properties of hot-rolled St60Mn steel. A thesis submitted to Department of Mechanical Engineering, University of Ibadan, Nigeria.

Obot, I. D. & Archibong A. E. (2016). Collapsed Buildings in Nigeria. *Global Journal of Engineering Research*, 15, 11–15.

Odusote, J. K. & Adeleke, A. A. (2012). Analysis of Properties of Reinforcing Steel Bars: Case Study of Collapsed Building in Lagos, Nigeria. *Applied Mechanics and Materials*. 4(8), 3052-3056.

Odusote, J. K., Shittu, W., Adeleke, A. A., Ikubanni, P. P. & Adeyemo, O. (2019). Chemical and Mechanical Properties of Reinforcing Bars from Local Steel Plants. *Journal of Failure Analysis and Prevention*, 19(4), 1067-1076.

Oguzie, E. E., Adindu, C. B., Enenebeaku, C. K., Ogukwe, C. E., Chidiebere, M. A. & Oguzie, K. L. (2012). Natural products for materials protection: mechanism of corrosion inhibition of mild steel by acid extracts of Piper guineense. *The Journal of Physical Chemistry*, 116(25), 13603-13615.

Oke, A. E. (2015). An Examination of the Causes and effects of Building collapse in Nigeria. *Journal of Design and Built environment*, 9, 37-47.

Olajumoke, A. M., Oke, L. A., Fajobi, A. B. & Ogedengbe, M. O. (2009). Engineering Failure Analysis of a Failed Building in Osun State, Nigeria. *Journal of failed analysis and Prevention*, 9, 8-15.

Olanitori, L. M. (2011). Causes of structural failures of a building: Case study of a building at Oba-Ile, Akure. *Journal of Building Appraisal*, 6(3), 277-289.

Oliveira, V. B., Frez, A. M., Guimarães, O. C., Carlos, L. C. & Viana, S. C. (2018). Application of a homemade procedure for manufacturing of a rod mechanical spare part. *Journa of Materials Research and Technology,* 7(4), 487-491.

Omenihu, F. C., Onundi, L. O. & Alkalj, M. A. (2016). An Analysis of Building Collapse in Nigeria from 1971 to 2016: Challenges for stakeholders. *Annals of Borno, University of Maiduguri.*

Oyedele, O. A. (2018). A Study of Control measures of Building collapse and in Lagos state, Nigeria. *International Gymnastics Federation (FIG) Congress, Istanbul, Turkey, May 6-11*.

Oyelade, A., Fapohunda, C. & Dixon, O. (2013). Effects of Source of Reinforcement on Microstructure and Strength Characteristics of Reinforced Concrete Beams. *Civil and Environmental Research*, 3(9), 26.

Peng, L., Feng, Y., Lv, P., Lei, D., Shen, Y., Li, Y. & Feng, W. (2012). Transparent, conductive, and flexible multiwalled carbon nanotube/graphene hybrid electrodes with two three-dimensional microstructures. *The Journal of Physical Chemistry*, 116(8), 4970-4978.

Ramkumar, T., Madhusudhanan, S. & Rajendran, I. (2020). Effect of Nickel on the Microstructure, Mechanical and Tribological Properties of Austempered Ductile Cast Iron for Steering Knuckle Applications. *Archives Metallurgy and Materials*, 65(1), 15-25.

Rekha, S. & BupeshRaja, V. K. (2010). Review on Microstructure Analysis of Metalsand Alloys Using Image Analysis Techniques. *Materials and Engineering*, 197(1), 1-5.

Royset, J., Rodland, M., Tundal, U. & Reiso, O. (2008). Effect of Alloy Chemistry and Process Parameters on the Extrudability and Recrystallization Resistance of 6082 Aluminum Alloy. *Proceedings of 9th International Aluminum Extrusion Technology Seminar and Exposition*.

Rozniata, E. & Dziurka, R. (2015). The transformation in Hypoeutectoid steels Mn-Cr-Ni. *Archives of Metallurgy and Materials*, 60(2), 497-502.

Shi, X. S., Collins, F. G., Zhao, X. L. & Wang, Q. Y. (2012). Mechanical properties and microstructure analysis of fly ash geopolymeric recycled concrete. *Journal of hazardous materials*, 237, 20-29.

Sieczkowski, K., Adamiec, J. & Sawicki, G. (2015). The structure and properties of mixed welded joints made of X10NiCrAlTi32-21 and X6CrNiMoTi17-2 steels. *Archives of Metallurgy and Materials*, 60(3), 1517-1525.

Sinaie, S., Heidarpour, A. & Zhao, X. L. (2014). Mechanical properties of cyclically-damaged structural mild steel at elevated temperatures. *Construction and Building Materials*, 52, 465-472.

Stephen, I. D., Olatunde, I. S. & Oluwashina, P. G. (2014). Effect of Copper on Microstructure and Mechanical Properties of Construction Steel. *International Journal of Structural and Construction Engineering*, 8(8), 785-789.

Stradomski, Z., Stachura, S. & Stradomski, G. (2013). Fracture Mechanisms in Steel Castings. *Archives of Foundry Engineering*, 13(3), 88–91.

Wasiu, J., Oyebode, O. J. & Adebayo, B. V. (2018). Causes of Building collapse and Prevention in Nigeria. Nigerian Institute of Civil Engineers, *11th International Conference and Annual General Meeting, 2018,* Afe Babalola University, Ado-ekiti.

Yunlong, B., Yikun, L., Nannan, S., Xiuhong, K., Dianzhong, L. & Yiyi, L. (2012). Chemical Compositions, Microstructure and MechanicalProperties of Roll Core used Ductile Ironin Centrifugal Casting Composite Rolls. *Journal of Material Science and Technology*, 28(9), 853–858.

Zhang, X., Fan, X., Yan, C., Li, H., Zhu, Y., Li, X. & Yu L. (2012). Interfacial microstructure and properties of carbon fiber composites modified with graphene oxide. *Applied materials & interfaces*, 4(3), 1543-1552.

APPENDIX A

Elemental composition of the Reinforced Steel from the Collapsed Building

Plate I: Metallographic image of ABJ 01

Element Name	Element Number	Element Symbol	Atomic Conc.	Weight Conc.
Iron	26	Fe	86.53	85.17
Chlorine	17	Cl	1.92	1.27
Sodium	11	Na	1.57	0.67
Silicon	14	Si	1.52	0.80
Sulfur	16	S	1.25	0.75
Potassium	19^2	K	1.13	0.82
Phosphorus	15	P	1.06	0.62
Aluminium	13	Al	0.95	0.48
Calcium	20	Ca	0.82	0.61
Carbon	6	C	0.63	0.14
Silver	47	Ag	0.63	1.27
Titanium	22	Ti	0.57	0.51
Chromium	24	Cr	0.54	0.52
Tin	50	Sn	0.37	0.82

Vanadium	23	V	0.32	0.31
Oxygen	8	O	0.20	5.31
Nickel	28	Ni	0.00	0.00
Copper	29	Cu	0.00	0.00
Zinc	30	Zn	0.00	0.00

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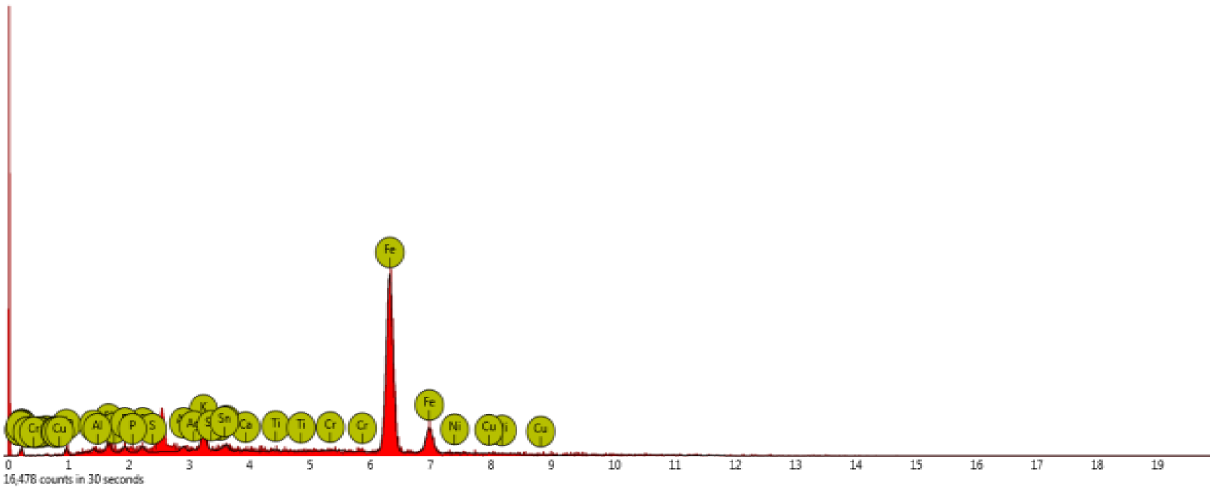
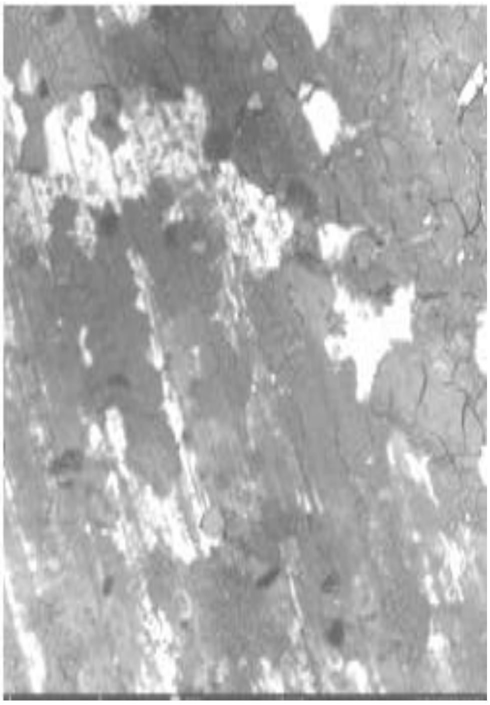


Plate II: Metallographic image of ABJ 02

Element Name	Element Number	Element Symbol	Atomic Conc.	Weight Conc.
Iron	26	Fe	82.78	81.88
Chlorine	17	Cl	3.75	2.53
Sodium	11	Na	2.49	1.09
Silicon	14	Si	2.33	1.24
Potassium	19	K	2.07	1.54



Aluminium	13	Al	1.37	0.70
Sulfur	16	S	1.12	0.68
Calcium	20	Ca	0.94	0.73
Carbon	6	C	0.72	0.16
Silver	47	Ag	0.69	1.42
Phosphorus	15	P	0.67	0.39
Tin	50	Sn	0.55	1.23
Titanium	22	Ti	0.42	0.39
Oxygen	8	O	0.10	6.02
Cobalt	27	Co	0.00	0.00
Vanadium	23	V	0.00	0.00
Chromium	24	Cr	0.00	0.00
Nickel	28	Ni	0.00	0.00
Copper	29	Cu	0.00	0.00

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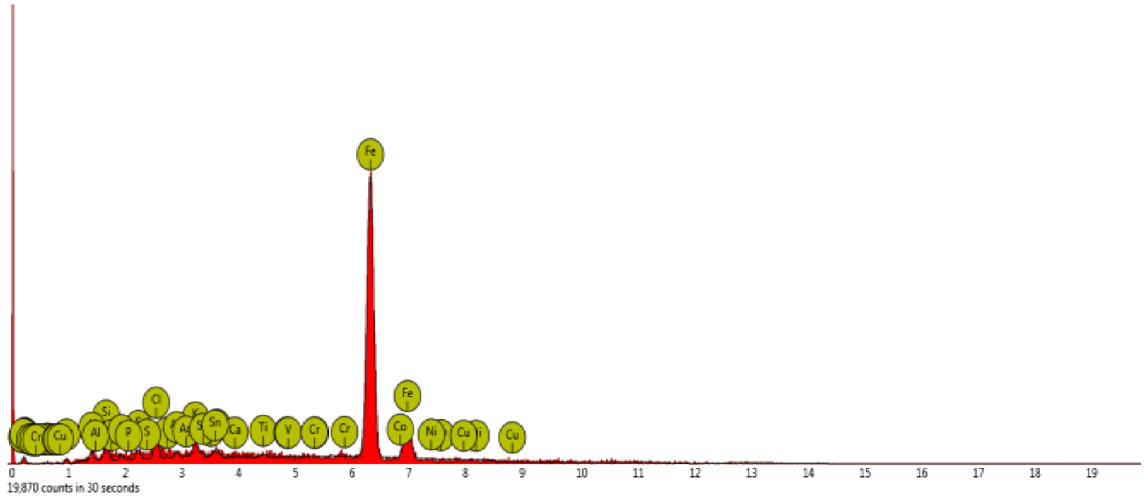

Plate III: Metallographic image of EDO

Element Name	Element Number	Element Symbol	Atomic Conc.	Weight Conc.
Iron	26	Fe	81.75	82.47
Sodium	11	Na	5.84	2.58
Potassium	19	K	3.49	2.62
Silicon	14	Si	1.68	0.91
Phosphorus	15	P	1.19	0.71
Calcium	20	Ca	1.11	0.87
Carbon	6	C	1.10	0.25
Sulfur	16	S	1.06	0.65
Silver	47	Ag	0.84	1.74
Aluminium	13	Al	0.80	0.42
Tin	50	Sn	0.50	1.13
Oxygen	8	O	0.34	5.37
Titanium	22	Ti	0.31	0.28
Chromium	24	Cr	0.00	0.00
Nickel	28	Ni	0.00	0.00
Copper	29	Cu	0.00	0.00

Element Name **Element Number** **Element Symbol** **Atomic Conc.** **Weight Conc.**

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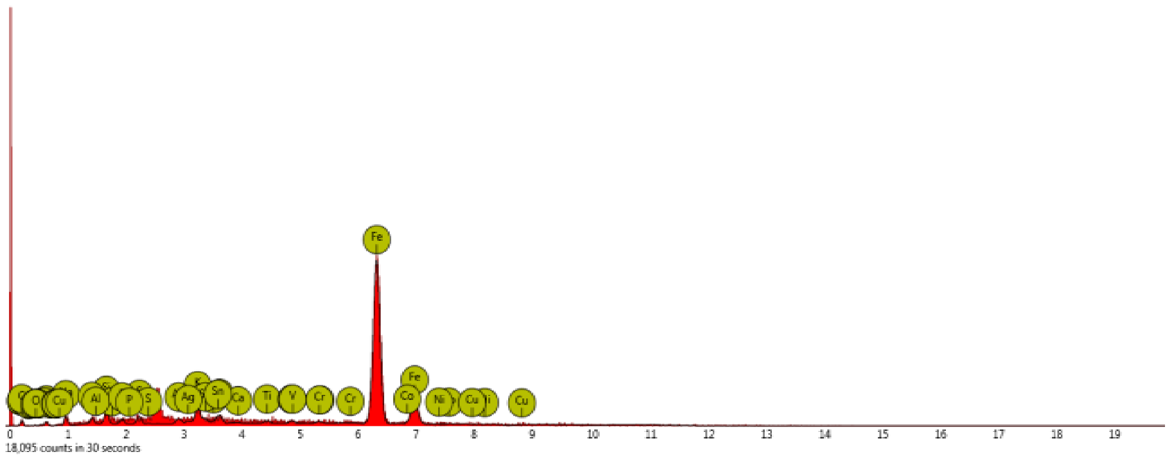
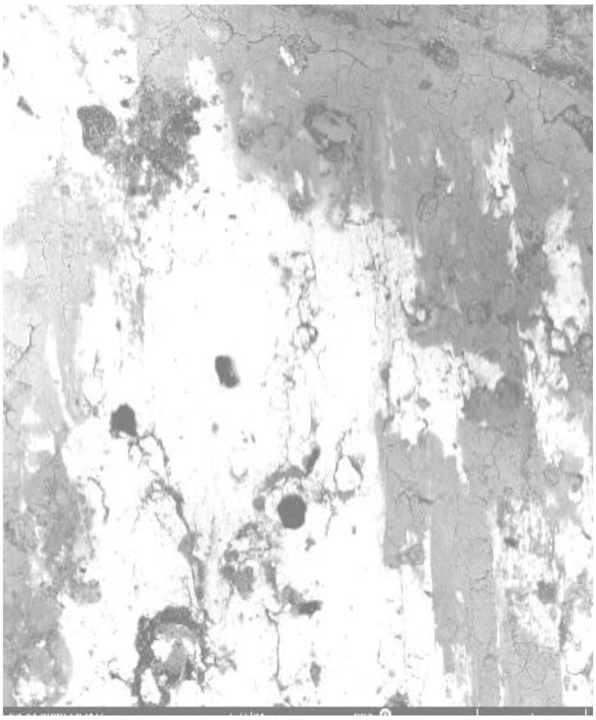
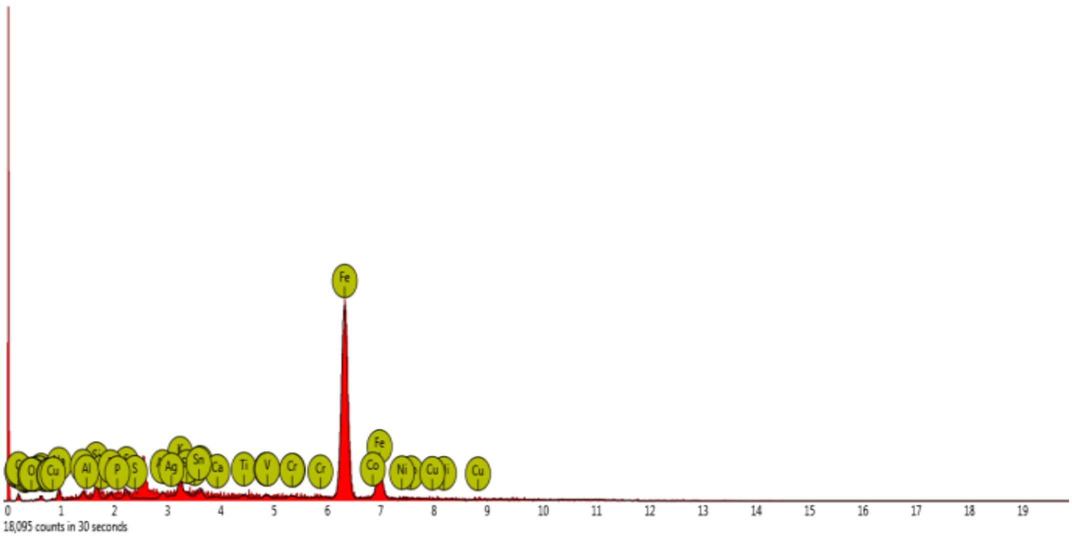


Plate IV: Metallographic image of IBD



Iron	26	Fe	78.01	79.32
Sodium	11	Na	6.75	3.00
Potassium	19	K	3.07	2.32
Silicon	14	Si	2.10	1.14
Aluminium	13	Al	1.47	0.77
Calcium	20	Ca	1.39	1.06
Sulfur	16	S	1.38	0.86
Phosphorus	15	P	1.04	0.62
Tin	50	Sn	0.89	2.04
Silver	47	Ag	0.84	1.76
Carbon	6	C	0.83	0.19
Titanium	22	Ti	0.72	0.66
Vanadium	23	V	0.59	0.58
Chromium	24	Cr	0.56	0.57
Oxygen	8	O	0.36	5.11
Cobalt	27	Co	0.00	0.00
Nickel	28	Ni	0.00	0.00
Copper	29	Cu	0.00	0.00

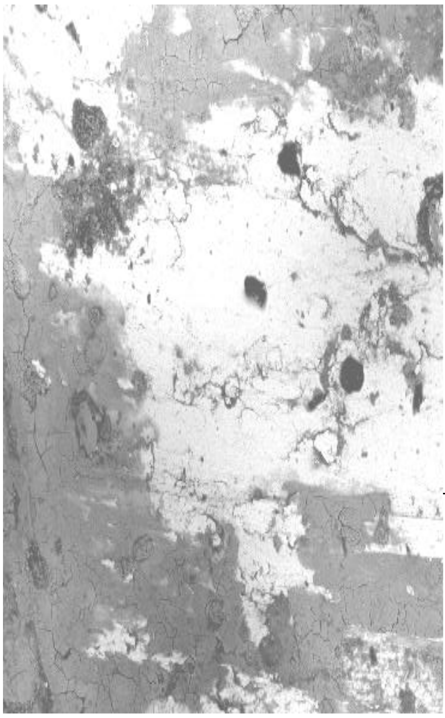
FOV: 537 µm, Mode: 15kV - Image, Detector: BSDFull, Time: FEB 28 2020 14:02



Element Name	Element Number	Element Symbol	Atomic Conc.	Weight Conc.
Iron	26	Fe	82.37	81.72
Sodium	11	Na	3.61	1.58

Chlorine	17	Cl	3.05	2.06
Silicon	14	Si	1.86	1.00
Carbon	6	C	1.62	0.37
Potassium	19	K	1.30	0.97
Chromium	24	Cr	0.89	0.89
Sulfur	16	S	0.84	0.51
Calcium	20	Ca	0.83	0.63
Phosphorus	15	P	0.74	0.44
Silver	47	Ag	0.61	1.25
Tin	50	Sn	0.60	1.37
Titanium	22	Ti	0.55	0.50
Vanadium	23	V	0.47	0.46
Oxygen	8	O	0.40	6.12
Aluminium	13	Al	0.26	0.13
Cobalt	27	Co	0.00	0.00
Nickel	28	Ni	0.00	0.00

PlateV: Metallographic image of JOS



FOV: 537 µm, Mode: 15kV - Image, Detector: BSD Full, Time: FEB 28 2020 14:19

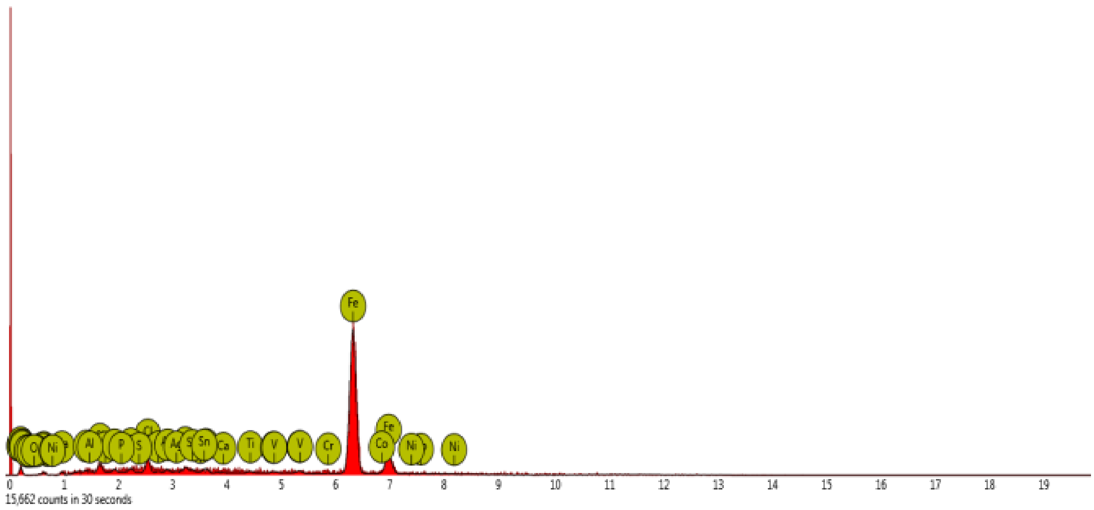


Plate VI: Metallographic image of KAN

Element Name	Element Number	Element Symbol	Atomic Conc.	Weight Conc.
Iron	26	Fe	78.01	85.98
Sodium	11	Na	6.75	3.00
Potassium	19	K	3.07	2.32
Silicon	14	Si	2.10	1.14
Aluminium	13	Al	1.47	0.07
Calcium	20	Ca	1.39	1.08
Sulfur	16	S	1.38	0.52
Phosphorus	15	P	1.04	0.42
Tin	50	Sn	0.89	0.02
Silver	47	Ag	0.84	0.06
Carbon	6	C	0.83	0.38
Titanium	22	Ti	0.00	0.00
Vanadium	23	V	0.00	0.00
Chromium	24	Cr	0.00	0.00
Oxygen	8	O	0.01	5.01
Cobalt	27	Co	0.00	0.00
Nickel	28	Ni	0.00	0.00
Copper	29	Cu	0.00	0.00

FOV: 537 μm, Mode: 15kV - Image, Detector: BSD Full, Time: FEB 28 2020 14:17

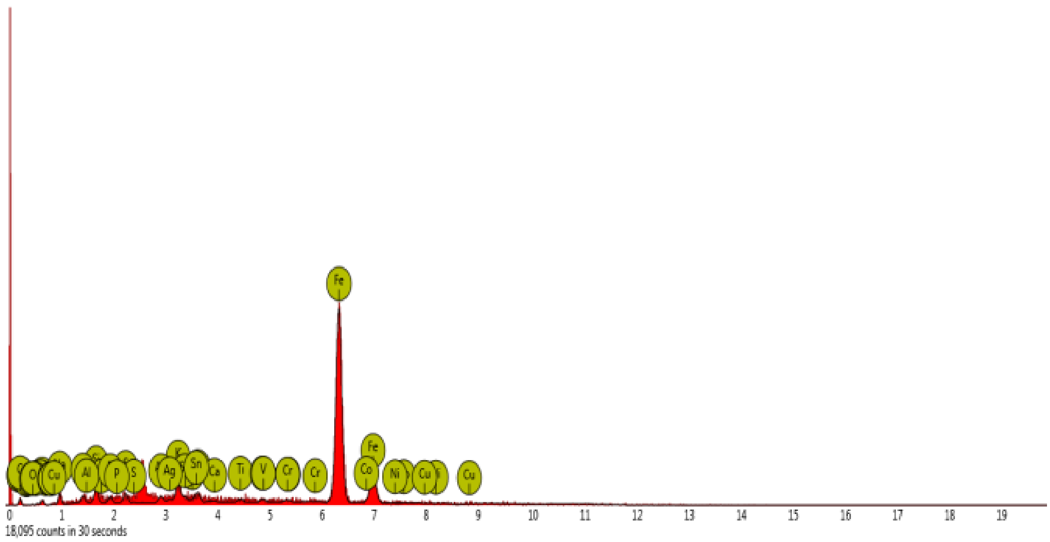
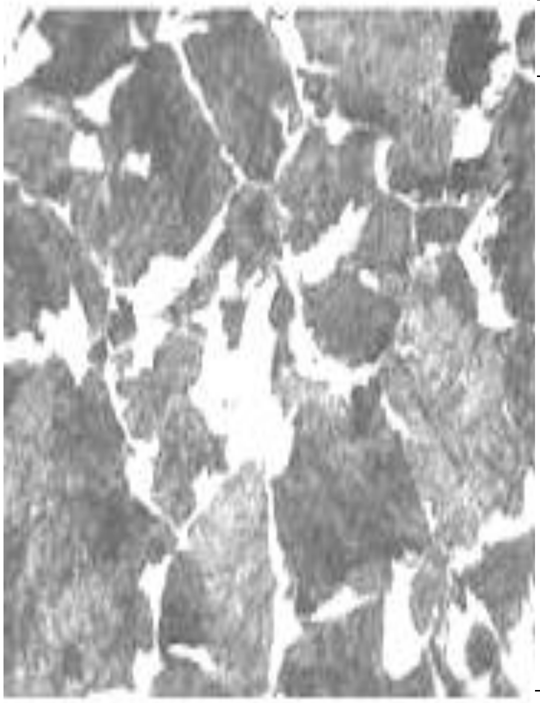


Plate VII: Metallographic image of LAG 01



Element Name	Element Number	Element Symbol	Atomic Conc.	Weight Conc.
Iron	26	Fe	81.75	82.70
Sodium	11	Na	5.84	2.49
Potassium	19	K	3.49	2.82
Silicon	14	Si	1.68	2.36
Phosphorus	15	P	1.19	0.50
Calcium	20	Ca	1.11	0.72
Carbon	6	C	1.10	0.38
Sulfur	16	S	1.06	0.69
Silver	47	Ag	0.84	0.74
Aluminium	13	Al	0.80	0.01
Tin	50	Sn	0.50	0.03
Oxygen	8	O	0.34	6.48
Titanium	22	Ti	0.31	0.08
Chromium	24	Cr	0.00	0.00
Nickel	28	Ni	0.00	0.00
Copper	29	Cu	0.00	0.00

FOV: 537 µm, Mode: 15kV - Image, Detector: BSD Full, Time: FEB 28 2020 14:22

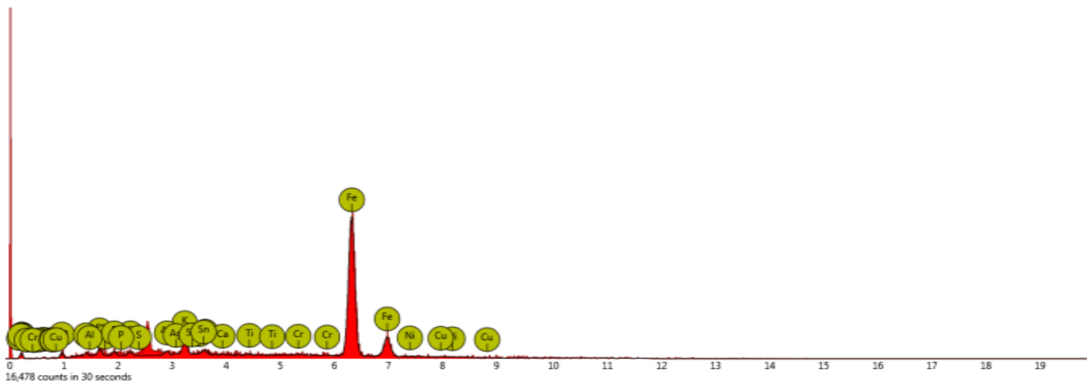
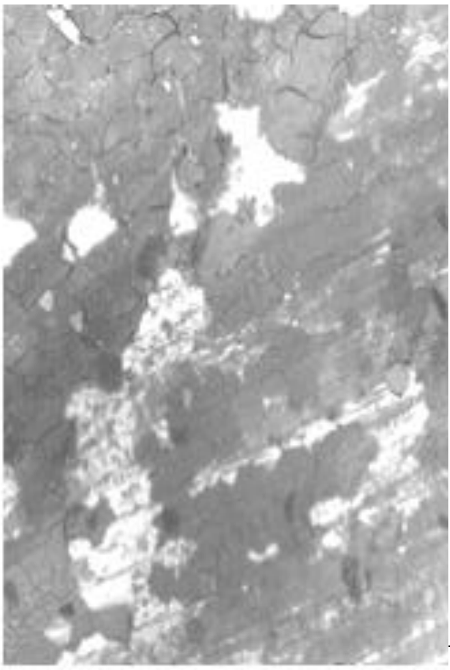


Plate VIII: Metallographic image of LAG 02



Element Name	Element Number	Element Symbol	Atomic Conc.	Weight Conc.
Iron	26	Fe	81.75	82.06
Sodium	11	Na	5.84	2.36
Potassium	19	K	3.49	2.82
Silicon	14	Si	1.68	0.91
Phosphorus	15	P	1.19	0.03
Calcium	20	Ca	1.11	0.08
Carbon	6	C	1.10	0.34
Sulfur	16	S	1.06	0.04
Silver	47	Ag	0.84	1.74
Aluminium	13	Al	0.80	0.42
Manganese	25	Mn	0.50	0.65
Oxygen	8	O	0.34	5.78
Molybdenum	42	Mo	0.31	0.22
Chromium	24	Cr	0.82	0.75
Nickel	28	Ni	0.68	1.80
Copper	29	Cu	0.00	0.00

FOV: 537 µm, Mode: 15kV - Image, Detector: BSD Full, Time: FEB 28 2020 14:08

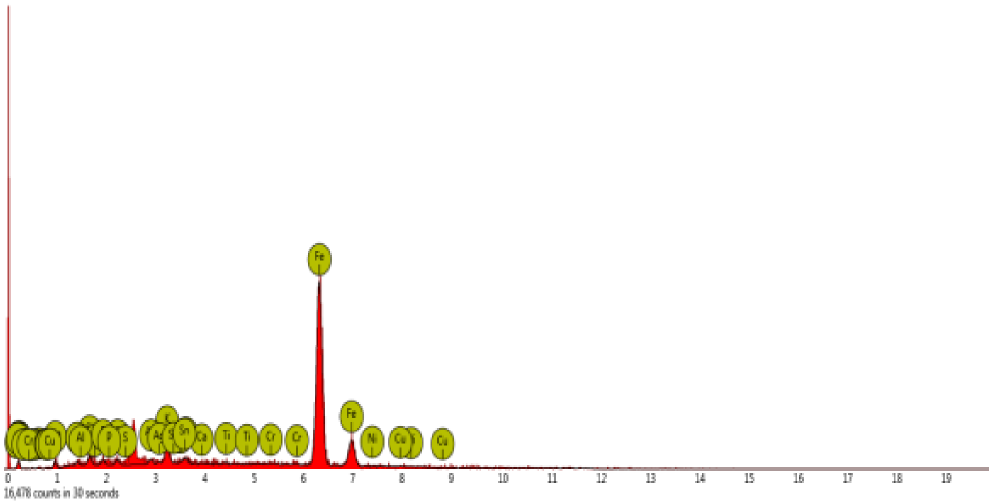
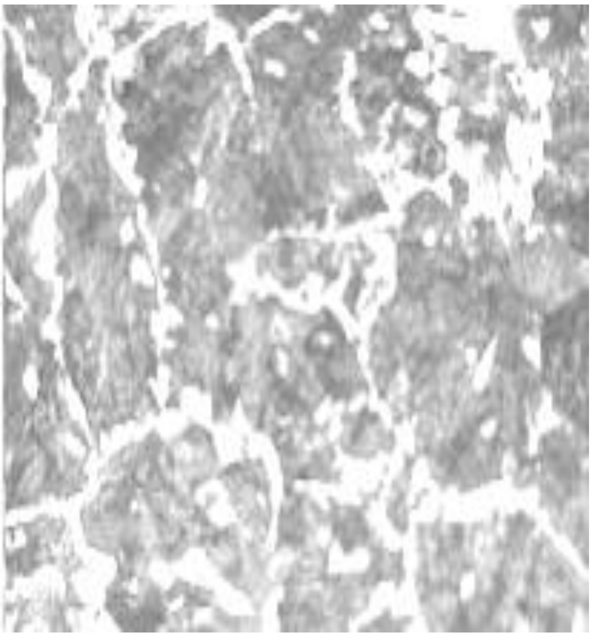
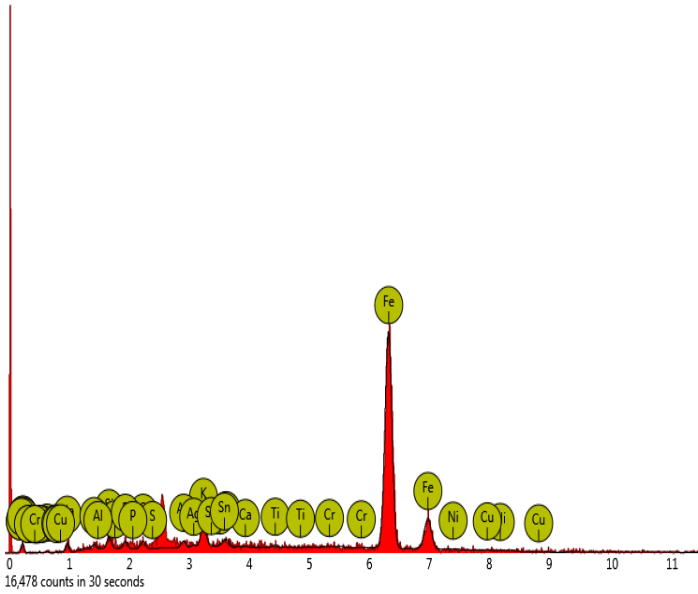


Plate IX: Metallographic image of LAG 03



Element Name	Element Number	Element Symbol	Atomic Conc.	Weight Conc.
Iron	26	Fe	81.75	87.98
Sodium	11	Na	4.34	2.75
Potassium	19	K	2.99	1.22
Silicon	14	Si	1.35	1.01
Phosphorus	15	P	0.19	0.01
Calcium	20	Ca	1.11	0.66
Carbon	6	C	1.80	0.35
Sulfur	16	S	0.41	0.03
Silver	47	Ag	0.84	1.32
Aluminium	13	Al	0.80	0.42
Tin	50	Sn	0.00	0.00
Oxygen	8	O	0.44	4.25
Titanium	22	Ti	0.00	0.00
Chromium	24	Cr	0.00	0.00
Nickel	28	Ni	0.00	0.00
Copper	29	Cu	0.00	0.00

FOV: 537 µm, Mode: 15kV - Image, Detector: BSD Full, Time: FEB 28 2020 14:25



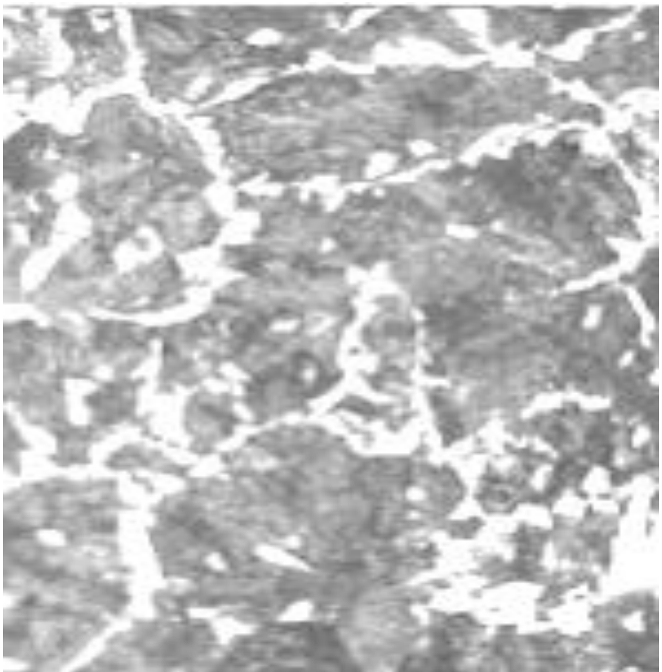
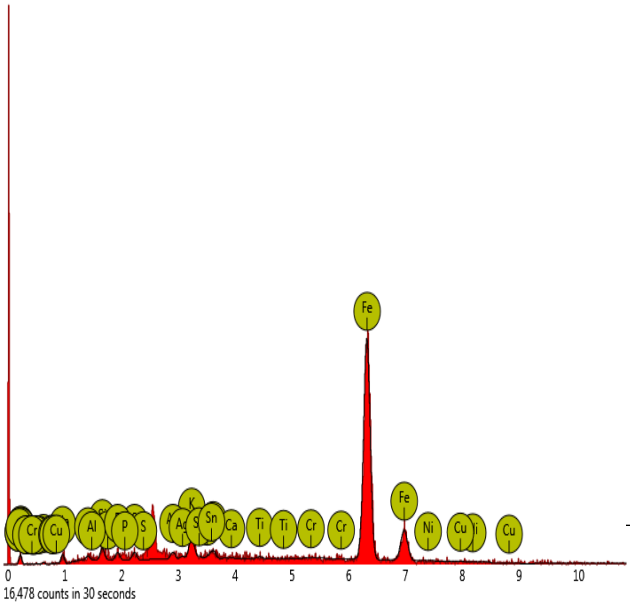


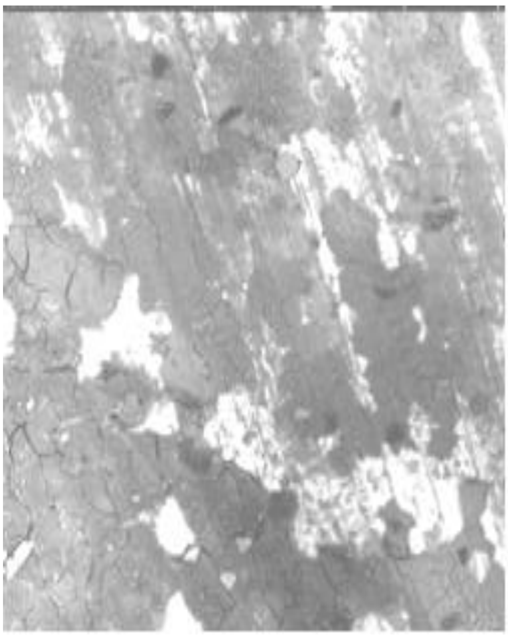
Plate X: Metallographic image of LAG 04

FOV: 537 µm, Mode: 15kV - Image, Detector: BSD Full, Time: FEB 28 2020 14:28



Element Name	Element Number	Element Symbol	Atomic Conc.	Weight Conc.
Iron	26	Fe	81.75	86.50
Sodium	11	Na	5.84	1.03
Potassium	19	K	2.35	1.86
Silicon	14	Si	1.37	0.46
Phosphorus	15	P	1.26	0.51
Calcium	20	Ca	1.11	0.86
Carbon	6	C	1.50	0.51
Sulfur	16	S	0.36	0.73
Silver	47	Ag	0.74	1.26
Aluminium	13	Al	0.80	0.32
Tin	50	Sn	0.00	0.00
Oxygen	8	O	0.34	4.60
Manganese	25	Mn	0.21	1.36
Chromium	24	Cr	0.00	0.00
Nickel	28	Ni	0.00	0.00
Copper	29	Cu	0.00	0.00

Plate XI: Metallographic image of PHC



Element Name	Element Number	Element Symbol	Atomic Conc.	Weight Conc.
Iron	26	Fe	81.75	81.52
Sodium	11	Na	5.84	2.96
Potassium	19	K	3.89	3.41
Silicon	14	Si	1.36	2.58
Phosphorus	15	P	1.19	0.65
Calcium	20	Ca	1.03	0.86
Carbon	6	C	1.52	0.45
Sulfur	16	S	1.16	0.70
Silver	47	Ag	0.39	0.26
Aluminium	13	Al	0.36	0.28
Tin	50	Sn	0.00	0.00
Oxygen	8	O	0.28	5.61
Manganese	25	Mn	0.26	0.72
Chromium	24	Cr	0.00	0.00
Nickel	28	Ni	0.00	0.00

FOV: 537 µm, Mode: 15kV - Image, Detector: BSDFull, Time: FEB 28 2020 14:32

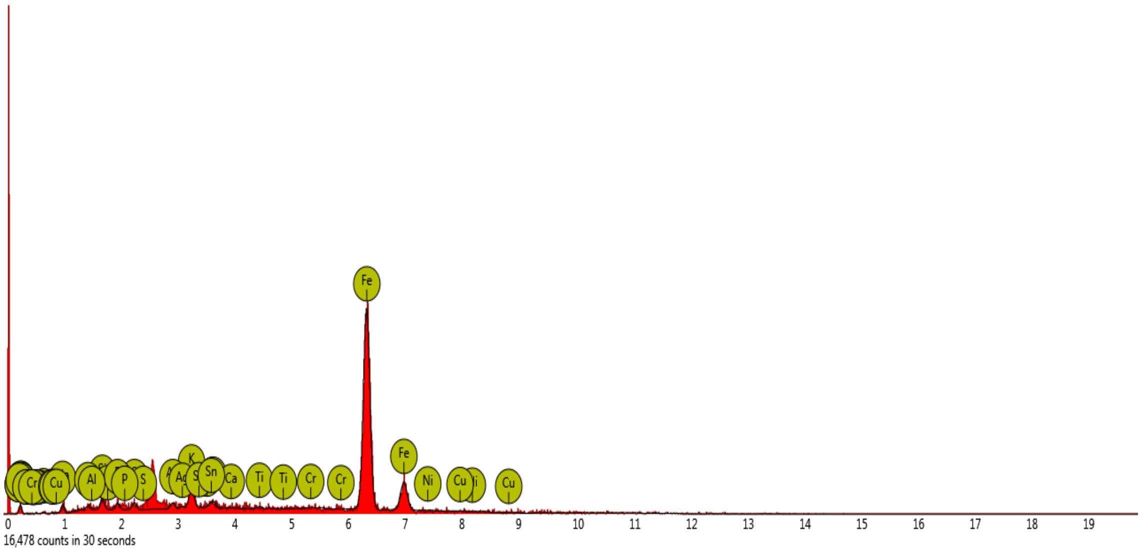
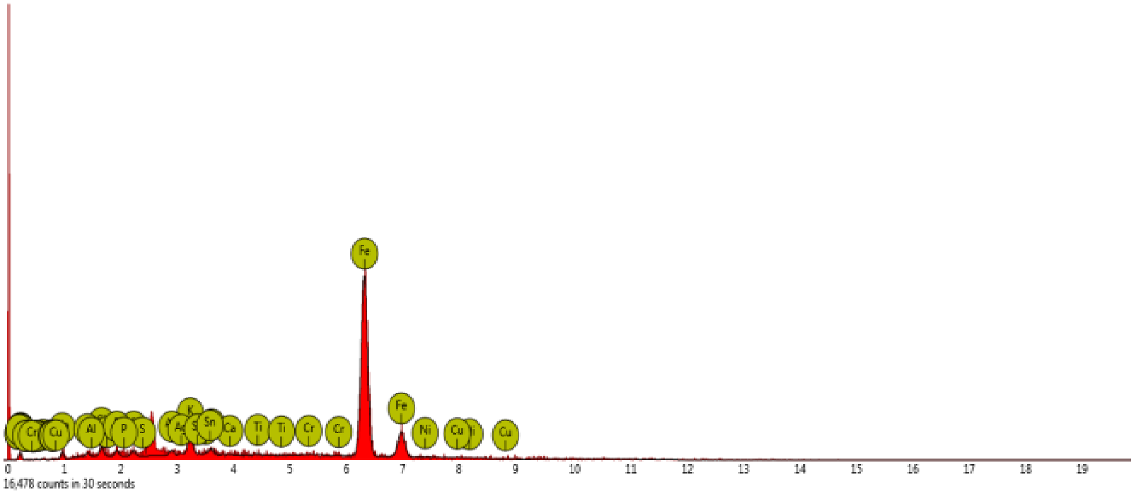


Plate XII: Metallographic image ofUYO:

Element Name	Element Number	Element Symbol	Atomic Conc.	Weight Conc.
Iron	26	Fe	81.75	87.27
Sodium	11	Na	3.96	2.57
Potassium	19	K	3.26	2.58
Silicon	14	Si	1.54	0.37
Phosphorus	15	P	0.15	0.06
Calcium	20	Ca	0.41	0.86
Carbon	6	C	1.11	0.42
Sulfur	16	S	0.16	0.03
Silver	47	Ag	0.69	0.51
Aluminium	13	Al	0.71	0.22
Tin	50	Sn	0.00	0.00
Oxygen	8	O	0.24	4.31
Manganese	25	Mn	0.26	0.80
Chromium	24	Cr	0.00	0.00
Nickel	28	Ni	0.00	0.00
Copper	29	Cu	0.00	0.00

FOV: 537 µm, Mode: 15kV - Image, Detector: BSDFull, Time: FEB 28 2020 14:35


Fe
Fe
Cr
Cu
Al
P
S
K
Ag
S
Sn
Ca
Ti
Ti
Cr
Cr
Ni
Cu
Cu
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
16,478 counts in 30 seconds

APPENDIX B

TESTING MACHINES

Figure A.1: Tensile Testing Machine

Figure A.2: Hardness Testing Machine

Figure A.3: Sampling Procedure

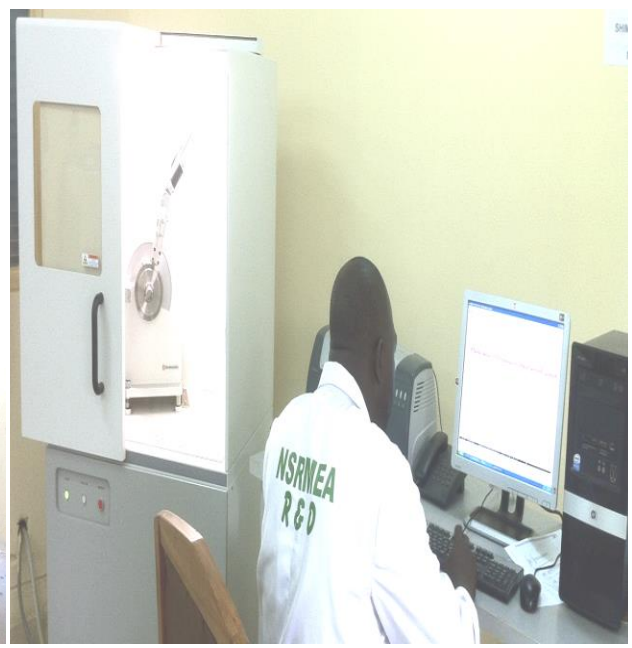
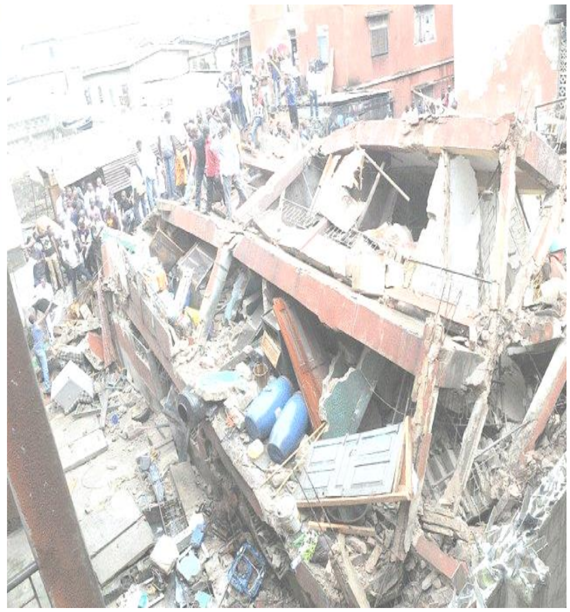


Figure A.4: NSRMEA Laboratory

APPENDIX C

COLLAPSED BUILDING SITES




DOOSAN