INVESTIGATION OF FLEXURAL STRENGTH OF REINFORCED CONCRETE BEAMS IN RWANDA

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Investigation of Flexural Strength of Reinforced Concrete Beams in Rwanda

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DECLARATION

This thesis is my original work and has not been submitted for a degree in any other university.

Signature**……………………………………….** Date………………………………..

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This thesis has been submitted for examination with our approval as university supervisors

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DEDICATION

This work is dedicated to

My Beloved Family:

My Wife Angelique;

My Daughter - Treasure;

My Son - Timothy.

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First and foremost, I would like express my sincere appreciation to my supervisors, **Prof. (Eng) G. N. Mang'uriu** and **Prof. (Eng) Walter O. Oyawa** for their tireless and genuine guidance throughout this thesis. Thank you for supporting the cause.

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Finally, I would like to thank the Almighty God, who gave me the commitment, courage and tolerance to pass through various obstacles and come up with this thesis.

"Thank you, Lord,"

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ABBREVIATIONS AND SYMBOLS

ACI	American Concrete Institute
ARC	Australian Reinforcing Company
AS/NZS	Australian New Zealand Standard
ASTM	American Society for Testing and Materials
BOS	Basic oxygen steel making
BS	British Standard
CEV	Chemical Equivalency Value
CFRP	Contiguous Fiber Reinforced Polymer
CTD	Cold twisted deformed
EAF	Electric Arc Furnace
f_{cu}	Characteristic Strength of Concrete
f_y	Characteristic Strength of Steel Bars
GDP	Growth Domestic Product
G_k	Imposed Loads
GoHK	Government of Hong Kong
GoR	Government of Rwanda
HSC	High Strengths Concrete
HSS	High Strengths Steel
HYS	High Yield Steel
IS	Indian Standard
KIST	Kigali Institute of Science and Technology
MS	Mild Steel
Q_k	Dead Loads
RBS	Rwanda Bureau of Standards
RC	Reinforced Concrete
Rebars	Steel Reinforcing Bars
RRA	Rwanda Revenue Authority
SLS	Serviceability Limit State
TMT	Thermo mechanically treated
UDS	Ultimate Design Strength

UTS	Ultimate Tensile Strength
$\Upsilon_{12\text{-}10mm}$	High Yield Deformed Steel Bars with Nominal of Diameter 12 and 10 mm
Υ_m	Partial Safety Factor for Materials
YS	Yield Strength

ABSTRACT

Present infiltration of substandard steel reinforcing bars on local market have had a serious concern and suspicion on strength and stability of buildings and other engineering structures that are being built with them. Some buildings have collapsed while others have developed signs of structural failures setting huge number of users into serious fears with subsequent vacation. Besides the failures in Rwanda, there has been disastrous incidences of collapsing buildings in neighboring countries where most of rebars are imported from and investigations have pinpointed substandard steel reinforcing bars. Primary objective of this study was to investigate the quality of steel reinforcing bars available in Rwanda and their performance on structural elements specifically reinforced concrete beams flexural behavior. So far only one research is known to have investigated quality of steel bars available in Rwanda with much focus on steel bars milled from scraps of which the results were equally disappointing. In this research 24 samples of steel reinforcing bars of 12mm and 10 mm Ѳ from four different sources available in Rwanda were randomly picked from warehouses. Each source were represented by six specimens, three of which were 12mm Ѳ and the other three of 10 mm Ѳ. Samples were assessed for their physical features compliance, mechanical and chemical properties were examined and finally RC beam flexural performance behavior investigated through laboratory tests. Results obtained showed that rebars physical feature standard code requirements were not met by 75%, while 48.5% of tested samples failed to meet high yield strength BS and RS EAS code prescription of 460N/mm2 only meeting mild steel bars limits. Of the failed 48.5% only 12.5% were Y12mm while the remaining 87.5% were Y10mm. The ultimate load of RC beams made of Y12 mm were determined to be in range of 114.6 KN to 142.6 KN while their respective flexural strength ranged from 25.7 N/mm2 to 33.4 N/mm2 as compared to design load of 111.8 KN and design flexural strength of 25.1 N/mm2 respectively. The flexural load of RC beam made of Y10 mm was found to be in range of 93 KN to 131.5 KN while their respective flexural strength ranged from 20.89N/mm2 to 32 N/mm2 as compared to design load of 78.2 KN and design flexural strength of 17.6 N/mm2 respectively. It is revealed from research that substandard rebars are still at large but more so with rebars that were not labelled at all which failed at 100%, all sample from S3 were not labelled at all for both Y12mm and Y10mm and failed to meet code requirements.

Keywords: Steel reinforcing bars, mechanical and chemical properties, quality control, RC beam, ultimate load, flexural strength and flexural performance behavior.

CHAPTER ONE

INTRODUCTION

1.1 Background

Rwanda is currently undergoing intensive development following many years it has lagged behind in different aspects of development, construction industry and research related inclusive. Reconstruction process and more particularly construction sector is at its climax and consequences of this high growth in construction sector is the high demand for construction materials, more particularly steel reinforcing bars. With construction material on highest demand, majority of which are imported from neighboring countries, namely Kenya, Uganda, Tanzania and other far countries like South Africa and Turkey. Rwanda has only two steel bars rolling mills; SteelRwa and Imani whose productions cannot meet the current demand.

In line with reconstruction, Rwanda has also adopted a land use planning policy of vertical development which calls for high rise buildings, like in most developing countries, high rise buildings are predominantly constructed with reinforced concrete with the main reinforcing material of concrete being reinforcing steel bars. This makes this unique material very important based on the role it plays in reinforcing structural elements in particular high rise buildings and other civil engineering infrastructure. It actually forms the major construction material component in construction industry, its quality determines the structural performance of the structural elements they reinforce.

According to African Development Bank in its Annual meeting of 19th -23rd May, 2014 held in Rwanda, there is high demand for housing units and the high rate of urbanization which is at 4% pa that has resulted in faster rate of growth of construction spending of 24% between 2008 to 2011 which is USD 500 million. This has seen a high demand for steel construction materials.

According to Rwanda Revenue Authority (RRA), there has been feasible increment of imported steel reinforcing bars, in 2006 total imports were 9,613 tons which grew to 28,617 tons in addition local production of 25,000 tons, making total consumption of

53,617 tons in 2016 from 9,613 tons in 2006. When the demand and consumption are high, there is equally high risk of substandard rebars in the market whether imported or locally produced and the high need for quality assessment and control.

Understanding of construction materials' engineering properties is of vital importance to construction industry stakeholders in the sense that their physical properties are expected to match the requirements of the design standards. Sometimes, rebars though sold on local market, designed and used in civil engineering structures and buildings as high yield strength bars of 460 N/mm^2, they are actually mild steel bars of 250N/mm^2 and consequences will be structural failure, collapses and claiming of innocent lives, definitely the cost is high.

Despite such an important role, its quality is never guaranteed, buildings have been collapsing at different levels some of which collapse during construction while others collapse in service. It has been established that the main cause of this dangerous and unfortunate incidences are poor quality materials, steel reinforcing bars being among them. In Rwanda, there has been so far few incidences of collapsed buildings, two in Kigali city which were still under construction and another one in Nyagatare town in Eastern province of the country, the investigations have implicated poor construction materials. There has been also other incidences of complex buildings developing structural cracks, some of these building were declared unfit for human occupation and consequently vacated for some time. In addition to the few incidences of collapsed buildings in Rwanda, there has been quite a number of building collapses in the neighboring countries where steel reinforcing bars are imported from and investigations conducted have pinpointed steel reinforcing bars' quality in doubt. This in itself causes suspicion in quality of steel reinforcing bars being used hence need to improvise effective quality control measures.

According to Senfuka et al. (2011), Ugandan steel industry is running short of both quality and quantity steel reinforcing bars resulting from insufficient steel scrap and consequently low quality scrap becomes unavoidable which produces poor quality of steel. Munyazikwiye Bukaragire. (2010) investigation on mechanical properties of steel reinforcing bars made from scrap picked randomly from Kenya and Rwanda construction sites, found out that 69% of re-bars tested failed to meet the standards, the study further revealed that the most of construction contractors have been using steel bars of less yield strength. According to the research, possible causes could be inconsistence in chemical composition among others in addition to number of rolling mills operating in the country that are not certified as reported by Kenya Bureau of Standards, which are suspected of producing substandard rebars.

Mwasame et al. (2012) *also* reported series of collapsed buildings in Nairobi and suburbs and investigations pinpointed poor construction materials among others, while Investigation on challenges of the quality of reinforced concrete buildings in Dar es Salaam, concluded that quality of designs and construction of reinforced concrete buildings was still a challenge mainly due to design deficiencies, lack of national building standards, inadequate monitoring of construction works by the regulatory authorities, lack of quality control for concrete ingredients as well as steel reinforcement (Rubaratuka, 2013). Therefore, in an attempt to investigate the structural performance of steel reinforcing bars available in Rwanda, a research was conducted on major mechanical properties that influence quality of steel bars such as tensile strength, bendability, ductility and weldability, and flexural performance of concrete beams reinforced with steel reinforcing bars from different sources available in Rwanda.

Findings from the study will act as an aid in improving the Rwanda construction industry by guiding construction stakeholders identify factors on quality of steel bars used in the sector and further guide quality control methods and various inspections that ensure quality of reinforcing steel bars sold on local market**.**

1.2 Statement of the Problem

In light of the fast growing construction industry in Rwanda to meet sustainable development envisaged in vision 2020, the structural stability status of buildings and other civil engineering structures might be questionable. This is because the quality of the steel reinforcing bars on local are in doubt.

Strength and stability of structures depend to large extent on the strength of reinforcing bars that reinforces their structural elements, which should be appreciated first through laboratory tests before being subjected into any use. Some buildings have collapsed while others have developed signs of structural instability setting users into serious fears. Besides the failures in Rwanda, the re-bars available in Rwanda are imported from neighboring countries that have experienced disastrous incidences of collapsing buildings and investigations have pinpointed at substandard construction materials including steel re-bars.

1.3 Justification of the Study

Most of steel reinforcing bars found in the open local market, by the visual inspection do not meet standard labeling, which develops suspicion from the outset. Further there are no significant studies that have been conducted on construction materials in general and to be specific on steel rebars used in Rwanda.

Construction companies and individuals purchase the steel bars from open local markets without any technical specification on the quality status and take them directly into use without being subjected into any property compliance investigation. It is said that most times manufacturers supply well tested quality reinforcing steel bars to big companies and contractors who make capital orders and who are known for being conscious of quality and who may possibly re-test the supplied reinforcing steel bars, while reinforcing steel bars supplied to local open market are intentionally made of poor quality.

In a research conducted by Munyazikwiye in 2010 on steel re-bars (Y) picked randomly from construction sites in Rwanda showed that 69% of selected sample failed below standard yield strength. There have been so far two major incidences of collapsed buildings one in Kigali suburb in 2009 which collapsed while under construction, fortunately at night and did not claim any life, the second on Eastern province in 2014 which killed six people injuring more than fourteen. Another university complex building at KIST University developed serious structural cracks in late 2014 and was declared not fit for use for some time. Other incidences of structural cracks have been registered in different buildings including modern market built six months ago by cooperatives.

The study intends to assess presence of substandard rebars within local market and propose quality control methods. It is beneficial to both government and individuals that quality of re-bars used in Rwanda be identified, harmonized to international standards and devise means of control based on experiences elsewhere obtained from this research.

1.4 Objectives of the Study

1.4.1 Main Objective

The primary objective of the study was to investigate the quality and structural performance of steel reinforcing bars available in Rwanda.

1.4.2 Specific Objectives

(i) To examine and determine physical, mechanical and chemical properties of steel reinforcing bars available in Rwanda.

(ii) To assess flexural performance behavior of concrete beams reinforced with steel bars.

(iii) To provide information on the quality status and propose possible quality control methods.

1.5 Research Questions

(a) Do steel reinforcing bars on the local market in Rwanda meet quality standard code requirements?

(b) What is their effect on the strength and stability of engineering structures they reinforce?

(c) Are there any regulating mechanisms to control the production and importation of substandard rebars, if at all they are there, are they effective?

1.6 Scope and Limitations

1.6.1 Scope

This study focused in Kigali, the capital city of Rwanda where most of complex buildings together with civil engineering structures are being built, it is also confined to testing of high yield deformed rebars type 1 of 12mm and 10 mm nominal diameter from four (4) different countries namely Kenya, Rwanda, Tanzania and Turkey whose steel reinforcing bars are predominantly being used in Rwanda.

The 12 mm and 10 mm diameters are the ones mainly used in reinforced concrete slabs which consume a bigger percentage of rebars used on buildings.

(i) Steel reinforcing bars was tested of tensile strength, bending characteristics, and chemical composition and the results were related to flexural performance results for possibility of any influence.

(ii) Concrete compressive strength test was conducted on eight concrete cubes of 150 x150 mm with aim of achieving at least 30 N/mm2 concrete strength, this concrete that was used for flexural and bonding tests.

(iii) Flexural strength test were performed on twenty four RC beam specimens reinforced with re-bars from four different sources available in Rwanda.

(iv) Bonding properties test was performed also on twenty four steel bar specimens from four different sources.

1.6.2 Limitations

The study was limited to high yield deformed rebars of 12mm and 10 mm nominal diameter because of available adequate laboratory equipments that could only provide good results on these diameters, which may not be the case with bigger diameters.

1.7 Thesis Organization

This thesis comprises five chapters:

The first chapter is an introduction which gives an overview of the background and problems related to steel reinforcing bars available in Rwanda and the need to meet its sustainable development. In the same chapter, rationale of the research is justified, specifies aim and objectives and finally elaborates on the research scope.

Chapter two gives brief literature review on major properties of steel reinforcing bars and impact on their structural performance in reinforced concrete structural members specifically beams.

Chapter three describes materials and methods used in this study to investigate the quality of steel reinforcing, illustrates approach to the research and examined RC beams structural performance through flexural test to meet the research objectives.

Chapter four presents the analysis and detailed discussion on the findings from the material properties investigation and their subsequent effect on RC beam flexural performance.

Chapter five concludes on major findings of the research and then recommends possible implementation measures and future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Consequences of using substandard steel reinforcing bars have been felt with different impacts in different countries through loss of confidence in construction sector and worst being loss of lives and properties.

Understanding of construction materials' engineering properties is of vital importance to construction industry stakeholders in the sense that their physical and mechanical properties such as tensile strength, bending and bonding are expected to match the requirements of the design standards. Sometimes, rebars though sold on local market, designed and used in civil engineering structures and buildings as high yield bars (460 N/mm^2) they are actually mild steel bars (250 N/mm^2) and consequences will be structural failure, collapses and claiming of innocent lives and definitely the cost is high (Singh & Kaushik, 2002).

Characteristic strength of steel reinforcing bars and performance behavior of concrete structural elements have been researched on elsewhere and several times with different objectives and results. This research tried to borrow from other related studies and researches conducted mainly in developing countries similar to Rwanda and assess whether similar problems existed and how they were handled and examine whether their findings would be related and beneficial to our situation.

Steel reinforcing bars and concrete are the two essential components in any reinforced concrete structure, the stability, safety and durability of such structures are directly dependent on their quality. In reinforced concrete members, concrete is the main body of the member which provides stiffness and resistance to compression loads, whereas reinforcing steel bars are placed in positions where tensile loads are expected, so that they encounter them appropriately. To be certain of such performances, required engineering properties of these materials are tested by performing well designed experiments in laboratories to assess whether results are similar as much as possible to the normal working conditions (Martin, 2006).

According to Nkem et al. (2014), a lot more needs to be done in examining of real causes of structural failures in developing countries particularly on concrete, steel reinforcing bars and reinforced concrete composite material. In an endeavor to assess behavior of steel reinforcing bars used in Lagos state which had experienced the highest number of building collapse of which 95 % were of RC structures, a research was conducted and one major problem identified that affects reinforcing steel bars was lack of sufficient information on resources and unstructured market, which makes it possibly hard to guarantee the quality of material.

Rebars of 12 and 16 mm diameter steel bars were investigated based on BS 4449: 1997 and Nigerian code NIS-117:2004, results indicated that 42% of 12mm diameter and 46% of 16mm diameter failed to meet the BS code, while 28% and 33% of 12 mm and 16mm respectively failed to meet the Nigerian code.

Nigerian construction industry market is said to be dominated by infested steel materials from different countries, manufactured and tested to different codes which results in unrealistic qualities that can hardly be guaranteed.

Opeyemi et al. (2013), confirmed that the predominance of substandard reinforcing steel bars in the Nigerian construction sector has highly contributed to increasing incidences of structural building failures. Ejeh and Jibrin (2012) conducted a tensile strength tests on reinforcing steel bars in the Nigerian construction industry and found out that, the characteristic strength for 60% of the tested samples of the locally produced steel reinforcing bars were low as compared to the 460N/mm^2 characteristic strength standard values specified in BS 4449: 1997, rather showing similarities of mild steel bars (250 N/mm^2).

Despite the above identified deficiencies in characteristic strength values of locally produced steel reinforcing bars, some tested samples recorded satisfactory percentage elongation and vice versa in the case of imported bars. Most of the steel reinforcement bar tested met the minimum ultimate to yield strength ratio specified in BS 4449: 1997. Jibrin and Ejeh (2013) conducted a chemical composition test of reinforcing steel bars in the Nigerian construction industry and found presence of impurities as evidenced by the traces of silicon, phosphorus, sulphur or their combination in most of the samples tested.

Despite that, all nineteen samples tested complied with code on carbon equivalent values. Evidence of products' technical information were absent in the open market where bulk of the products were sold to the construction industry, including local products. From the field survey carried out it was confirmed that only clients of corporate projects pay serious attention to materials testing at site for proper documentation.

Munyazikwiye (2010) in investigation on characterization and variability of mechanical properties of reinforcing steel bars made from scrap found out that 69% of bars from hardware stores failed to meet the requirements. Further, the survey revealed that major weakness in bars that contractors have been using was in low yield strength. According to the research possible causes of variability of mechanical properties of reinforcing steel bars were: the inconsistence in chemical composition, variation in microstructure and grain size. He further quoted Kenya Bureau of Standards having reported that 5% of rolling mills operating in the country being not certified.

Mwasame et al. (2012) reported series of collapsed buildings which included one in Nairobi on Ronald Ngala Street in January 2006, Kiambu town in October 2009, Embakasi in June 2011, Langata in June 2011, Ngara in July 2011, Luanda in September 2011 and in Bungoma town in April 2012. The causes of these building collapse in most cases were attributed to poor construction materials though with no tangible evidence.

In the research on safety and structural reliability of reinforced concrete buildings in Kenya, structural reliability analysis using VaP program was carried out on beams to determine their reliability index. Results showed that average structural reliability index of 1.43 corresponding to failure probability of 7.6359E-2. This implicates safety level of constructed frame buildings in Kenya using locally produced concrete and reinforcement steel being low when compared to acceptable international standards stated in BS4449:1997 which states 460N/mm^2.

This further indicates that buildings are vulnerable to collapse and a slightest provocation such an earthquake of moderate intensity, rainstorm or a strong wind will trigger collapse. It should also be noted that this safety level represents reinforced concrete buildings constructed under formal construction arrangements. The risk level could be higher in reinforced concrete buildings constructed under informal arrangements where building designs are not approved by relevant authorities and consequently poorer quality control and inspection is expected.

Figueroa (2014), surveyed 24 construction sites in Nairobi and 51 existing buildings in the metropolitan area of Nairobi. It was revealed that construction material results were often of less quality than the laboratory test results which eventually lead to structural instability of buildings. The survey further reported incidences of collapsed buildings in different countries and in relatively few years between 2006 and 2014. 17 in Kenya killing 82 people and causing 291 injuries, 1 Accra, Ghana, killing 12 people factory in Bangladesh that claimed over 1,100 people, a church in Nigeria that killed 44 persons, in addition to the death, the incidences witnessed quite a huge number of fatal injuries.

Nassaka (2016) in the independent magazine reported a number of collapsed buildings in different parts of Kampala: 2015 in Kansaga and Lungujja claming 5 lives, in 2013 down town Kampala killing 15 instantly with uncountable fatal injuries. Spencer (2016) indicated number of buildings that collapsed due to use of counterfeit materials, one in 2016 a six storey building at Kyaseka in Makerere in Uganda collapsed and 8 people lost their lives. In the same year a six storey residential building collapsed in Kenya and more than 33 people were reported dead. Again in 2013 a building collapsed in Nyagatare - Rwanda killing six people instantly (Tabaro, 2013).

Senfuka et al. (2013), reported a dangerous incidence of rise of the strength values of steel reinforcing bars that results from residual element contents and predicted likelihood of further increase with time as more and more scrap is recycled in the absence of industrial processes to remove such residues. They suggested the immediate solution to the problem as use of virgin ore and appreciated the current initiative of using sponge iron projects in some of the county’s steel industries which may be used in combination with scrap as pure tramp element free additions or as outright cleaner steel. The fact that the current steel standards are not very clear about the maximum strength values of the steel on the market is worrying**.**

Rubaratuka (2013) researched on challenges of the quality of reinforced concrete buildings in Dar es Salaam, concluded that quality of designs and construction of reinforced concrete buildings was still a challenge mainly due to design deficiencies, lack of national building standards, inadequate monitoring of construction works by the regulatory authorities, lack of quality control for concrete ingredients as well as steel reinforcement, lack of appropriate construction technology and inadequate supervision of the works. Nkem et al. (2014) noted that all efforts in carrying out a rigorous analysis and design and careful detailing will come to a naught if substandard materials still exist in construction sector, more so in the case of reinforcement where a plethora of different brands of reinforcement is available in the market, and more often than not, the quality of steel is taken for granted.

2.2 Concrete as Part of Reinforced Concrete Composite Material

2.2.1 Properties of Concrete and Factors Affecting them

Concrete is the most widely used construction material in the world and is mostly used with steel reinforcements giving rise to reinforced concrete material. It is obtained by mixing cement, fine aggregate, coarse aggregate and water in appropriate proportions. Strength, durability and other characteristics of concrete depend upon the properties of its ingredients, proportion of the mix and other controls during placing, compaction and curing.

The important engineering property of concrete that must be tested before being put into any use is its compressive strength which is usually determined by carrying out compression tests on 150 mm cube at 28 days of complete curing. Cubes should always be prepared using standard procedures laid down in BS EN 12390-1 2000. Concrete strength classes have been classified in the range of C20/25 and C50/60 and can be designed using BS 8110 (Chanakya, 2009).

Most times concrete is designed to meet specific requirements such as strength and durability under normal conditions of exposure. The two properties of concrete are duly dependent on grade of concrete, cement content and its grade, methods of construction and placement together with conditions of exposure. The most common defects that occur in concrete is cracking due to the weak tensile strength and is normally encountered by placement of reinforcing bars where cracks are most likely to develop (Nkem et al., 2014). Ghoneim, and El-Mihilmy (2008) underlines the main determinants of concrete compressive strength as water cement ratio, type of cement, aggregate properties, concrete age and curing duration; however the most dominating factor of all these is water cement ratio. The lower the water content the good workability in concrete and compressive strength.

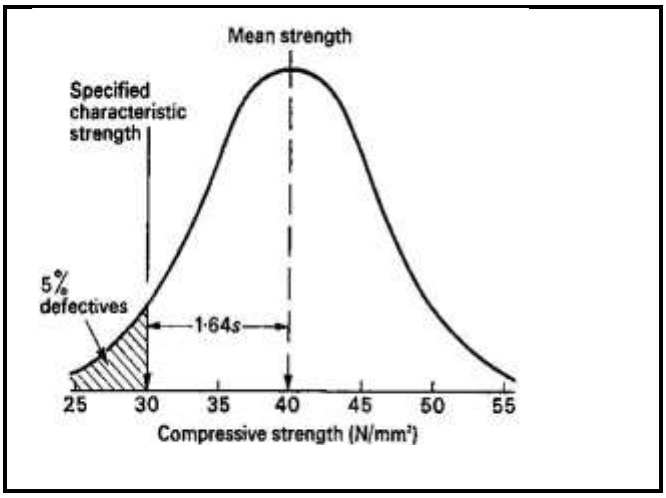
2.2.2 Concrete Mix Design

(i) Introduction

Concrete mix design is process of choosing appropriate ingredients of concrete that form appropriate ratios with aim of achieving concrete of desired workability, strength and durability, in any given environment in consideration of economical factors (Durocrete Engineering Ltd, 2009). Concrete can be designed for different grades ranging from 10 to 100 N/mm^2 and workability ranging from lowest possible slump of zero to 150 mm yet with the same basic ingredients only difference being their relative proportioning.

Different mix design methods exist with similar ways of arriving at proportions only with differing methods of calculation and help to arrive at the trial mix that will give required strength, workability and cohesion. Any mix design procedure will provide a first approximation of the proportions and must be checked by trial batches. The aim of the designer should always be to get concrete mixtures of optimum strength at minimum cement content and acceptable workability. During production of concrete there are inevitable variations not only in quantity but also in quality of materials used. This variability is measured by standard deviation *(S)* precisely given on normal distribution curve symmetrical about its mean *(M)* as shown on the Figure 2.1 below.

The standard deviation *(S)* is calculated from the standard equation given below (Marsh, 1997).



$$s = \sqrt{\frac{\sum (x-m)^2}{n-1}} \quad \text{................ (2.1)}$$

Where

x = an individual result
n = the number of results
m= the mean of the n results

Figure 2.1: Normal distribution curve for concrete strength design
Source: Marsh, (1997)

(ii) Types of Mixes

There are mainly three types of mixes: The nominal mixes which are of fixed cement-aggregate ratio that ensures adequate strength. They offer simplicity and under normal circumstances, have a margin of strength above that specified. Standard mixes which are nominal mixes of fixed cement-aggregate ratio by volume but vary widely in strength and may result in under- or over-rich mixes. And the designed mixes: whose performance is specified by the designer but the mix proportions are determined by the producer of concrete, except that the minimum cement content can be laid down. This is most rational approach to the selection of mix proportions with specific materials in mind possessing unique characteristics. The approach results in the production of concrete with the appropriate properties most economically. However, the designed mix does not serve as a guide since this does not guarantee the correct mix proportions for the prescribed performance.

(iii) Factors affecting the choice of concrete mix proportions

There are mainly five different factors affecting the concrete mix design based on requirements (Marsh, 1997). these include are:

(a) Compressive strength:

It is one of the most important properties of concrete and influences many other describable properties of the hardened concrete. The mean compressive strength required at a specific age, usually 28 days, determines the nominal water-cement ratio of the mix. The other factor affecting the strength of concrete at a given age and cured at a prescribed temperature is the degree of compaction.

(b) Workability:

The degree of workability required depends on three factors. These are the size of the section to be concreted, the amount of reinforcement, and the method of compaction to be used. For the narrow and complicated section with numerous corners or inaccessible parts, the concrete must have a high workability so that full compaction can be achieved with a reasonable amount of effort. This also applies to the embedded steel sections. The desired workability depends on the compacting equipment available at the site.

(c) Durability:

The durability of concrete is its resistance to the aggressive environmental conditions. High strength concrete is generally more durable than low strength concrete. In the situations when the high strength is not necessary but the conditions of exposure are such that high durability is vital, the durability requirement will determine the water-cement ratio to be used.

Factors that affect durability may be both external and internal:

External factors range from environmental actions such as extreme temperature, abrasion and electrostatic actions on concrete, and chemical attack such as cement carbonation, chloride-ion penetration and sulphate. While internal factor originates from Alkali-aggregate reaction, volume change resulting from thermal properties of the differences between aggregates and cement paste and finally water-cement ratio (Malay, 2019).

(d) Maximum nominal size of aggregate:

In general, the larger the maximum size of aggregate, the smaller is the cement quantity requirement for a particular water-cement ratio, because the workability of concrete increases with increase in maximum size of the aggregate.

However, the compressive strength tends to increase with the decrease in size of aggregate. IS 456:2000 and IS 1343:1980 recommends that the nominal size of the aggregate should be as large as possible.

(e) Grading and type of aggregate:

The grading of aggregate influences the mix proportions for a specified workability and water-cement ratio. The Course the grading the leaner will be the mix which can be used. Very lean mix is not desirable since it does not contain enough finer material to make the concrete cohesive. The type of aggregate influences strongly the aggregate-cement ratio for the desired workability and stipulated water cement ratio. An important feature of a satisfactory aggregate is the uniformity of the grading which can be achieved by mixing different size fractions.

(iv) Quality control:

The degree of quality control can be estimated statistically by the variations in test results. The variation in strength results from the variations in the properties of the mix ingredients and lack of control of accuracy in batching, mixing, placing, curing and testing. The lower the difference between the mean and minimum strengths of the mix the lower will be the cement-content required. The factor controlling this difference is termed as quality control.

(v) Concrete mix design procedures

Concrete mix design passes through different steps which involves using both standard tables and graphs specifically when using **DOE** (British) Mix Design Method, that is commonly used in Rwanda, (Marsh, 1997).

2.3 Reinforcing Steel Bars as Part of Reinforced Composite Material

2.3.1 Introduction

Steel reinforcing bars are the back bone of reinforced concrete structures, and therefore, their strength has a major contributing factor to the load bearing capacity of such. In most cases, engineers tend to take the properties of reinforcing steel bars for granted by not being conscious of stated strength and re-test the rebars to ascertain the labelled values, most times they are influenced by price than determining properties. To be able to take informed decisions about the quality of steel reinforcing bars in a holistic manner, it is imperative that structural engineers are conversant with the relevant steel engineering properties that have a bearing on the structural performance of the steel reinforcing bars (Nkem et al., 2014).

2.3.2 Main Mechanical Properties of Steel Reinforcing Bars

(i) Introduction

Mechanical properties of a material are used to determine its suitability for a specific application. It is about behavior of materials under applied forces which may be in form of stress or strain. There are basically three forms of stresses related to the nature of the deforming force applied on the material. They may be tensile, compressive or shear in nature. The National Institute of Standards and Technology-NIST (2014*)* of USA elaborates tensile properties that best define strength as: yield strength; tensile strength;

uniform elongation and total elongation and then ratio of tensile strength to yield strength. The primary property of steel reinforcing bars that must be known is its tensile strength capacity which can be determined using the procedure laid down in BS EN 10002. BS 8110 (1997) recommends design that is based on the characteristic strength of the reinforcement and gives typical values for mild steel and high yield strength steel reinforcement, where high-yield strength reinforcement is mostly used in practice (Chanakya, 2009).

UK CARES part 3 (2011) also enumerates main performance characteristics required of steel reinforcing bars as: tensile strength which includes yield strength and elongation; bend/ rebend which evaluates ductility; fatigue that is governed primarily by stress concentration; bond properties which are dependent of rib pattern and size and finally weldability most times defined in terms of chemical equivalency value (CE).

Ghoneim and El-Mihilmy (2008) further elaborate on major steel properties that may be determined from the stress-strain curve of specimen bars with applied tension force up to failure. These are mainly ultimate tensile strength, the yield strength and the modulus of elasticity. Specifically, modulus of elasticity of steel is determined from the slope of the stress strain curve in the elastic region and is normally 200 GPa.

Samsudi (2011) differentiates between engineering stress-strain curve and true stress – strain curve. True stress being a result of applied force divided by actual area of the cross section through which force operates.

This scenario considers change in cross section as the force changes in its intensity, it is always larger than nominal stress that act perpendicular to the cut surface. On the other hand, the engineering stress-strain curve does not give a true indication of the deformation characteristics of a metal because it is entirely based on the original dimensions of the specimen despite continuously dimensional change during the test.

Balogun et al. (2009) acknowledges good strength, bonding with concrete, thermal expansion characteristics and bendability as prime properties that brings about efficiency of steel re-bars to serve well as reinforcing materials of concrete structures.

Any increase in the strength characteristics of steel will enhance the reliability and durability of the structure it is used in.

The durability of reinforced concrete structures that is dependent mainly on strength of steel bars is the in the strength of steel, chemical composition plays an important role in this respect **(**Basu, 2004).

(ii) Tensile Strength/ Ultimate tensile strength (Rm)

This is the maximum stress which the steel can carry, it is obtained by dividing the maximum load that the specimen sustains by the nominal bar area. It is not used directly in reinforced concrete design; however, the ratio of tensile strength to yield stress is important to ensure a ductile failure mechanism (ARC, 2010). Akintoye et al. (2013) carried out an investigation on reinforcing bars obtained from six sources in Nigeria, four of which were locally manufactured and named from L1 to L4 while the other two were imported and named from F1 and F2, to determine their strength adequacy for structural applications, with a view to curbing down the incidence of structural failures attributable to the use of substandard steel reinforcing bars. The results of tensile test are presented in the Table 2.1 below.

Table 2.1: Tensile properties of locally made and imported rebars in Nigeria

	Diameter (mm)	**Steel manufacturer**						**BS 4449 Requirement -1997**
		L_1	L_2	L_3	L_4	F_1	F_2	
Yield strength	12	459.38	491.16	470.93	459.38	586.5	496.94	460
(N/mm^2)	16	396.54	403.04	546.05	486.05	594.81	559.05	
Tensile strength	12	574.94	676.07	655.84	618.28	765.63	681.84	N/A
(N/mm^2)	16	541.18	559.05	680.94	604.56	721.57	687.44	
% Bar	12	13.83	11.66	10.16	22.16	10.00	9.3	14
elongation	16	14.16	21.83	13.83	17.33	15.16	13.33	
Stress ratio	12	1.25	1.38	1.39	1.35	1.31	1.37	1.08
(Rm/Re)	16	1.36	1.39	1.25	1.24	1.21	1.23	

It was observed that only two of the locally sourced steels and all the foreign steel met the minimum requirements for 12 mm bars. According to BS 4449 (1997), the minimum percent elongation after fracture is limited to 12%. Out of the steel samples that were locally sourced, only two and none of the foreign sourced steel met the requirements for 12mm steel bar. However, the ratio of the tensile strength to the yield strength defined as the stress ratio, for all the steel specimens exceeded the minimum specified by the code.

(ii) Yield Strength

Yield strength is defined as the amount of stress that a material can undergo before changing from elastic into plastic deformations. It is the minimum stress that produces permanent plastic deformation. For high yield strength reinforcing steel, the code BS 4449 (1997) stipulates minimum strength of 460N/mm^2 while BS 4449 (2005) updated to 2009 stipulates steel grade 500 with minimum yield strength of 485 N/mm^2 and maximum yield strength of 650 N/mm^2.

Government of Hong Kong construction standard -CS2 (2018) gives the same values as BS 4449- 2005 updated to 2009. The yield stress of steel bar is determined by stretching a sample of appropriate length into a tensile-testing machine, the amount by which the length increases is called strain and is directly proportional to the applied load in early stage elastic of zone.

The ‘yield point’ of the steel is reached when strain is no longer directly proportional to the stress applied to the bar. Beyond the yield point the bar behaves plastically and is permanently deformed. Once the yield point is reached, the strain increases rapidly for a minor increase in the applied load and the steel is said to have yielded. After maximum tensile strength has been reached, the capacity of the bar reduces and necking is visible and eventually the bar breaks.

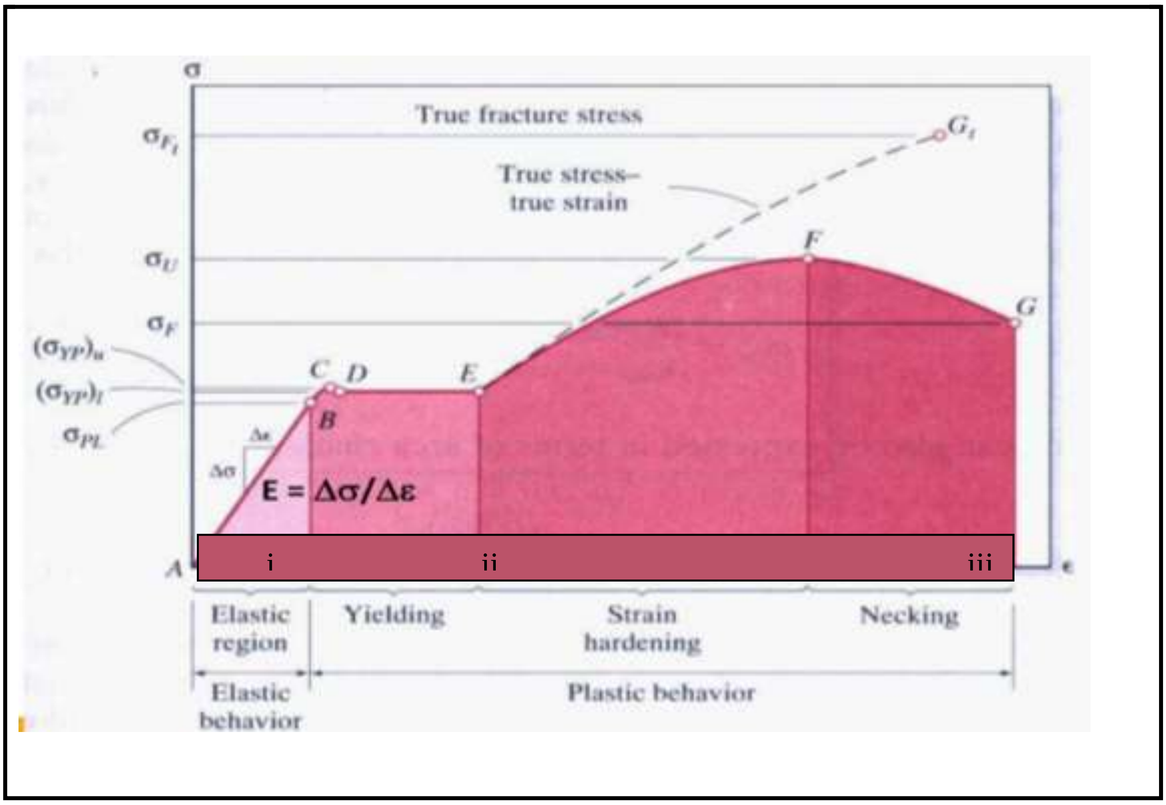


Figure 2.2: Complete stress- strain area diagram for high yield steel bars.
Source: Sakran,S-*Materials Science: SSP 2412.*

(iii) Ductility

Ductility of a material is its ability to plastically deform without fracturing when placed under a tensile stress that exceeds its yield strength. The most common measure of ductility is the percentage of change in length of a tensile sample after breaking which is generally reported as % elongation. **(**Ramsdale, 2006).

Ductility is said to be a desirable structural property because it allows stress redistribution and provides warning in case of failure. This is a property that is equally applicable in reinforced concrete structures that is only achieved in case of under reinforced design where failure is initiated by yielding of the steel reinforcement followed by considerable deformation at no substantial loss of load carrying capacity through concrete crushing and ultimate failure.

AS/NZS- 4671 (2001) has categorized ductility into three grades for steel reinforcing bars which are low, normal, and high/earthquake or seismic normally represented by letters L, N and E respectively. Ductility measurement has also been categorized as uniform elongation that provides a measure of the ability of the reinforcement to deform, both elastically and plastically, before reaching its maximum strength, and through the tensile strength / yield stress ratio which is a measure of the reinforcement's ability to work harden when undergoing plastic deformation.

This further indicates that strength of the steel increases when it is loaded beyond its yield strength. Ductility property requires a slight link to brittleness which is its tendency to fail upon load application without going through plastic deformation, the material breaks or structure fails so suddenly without warning.

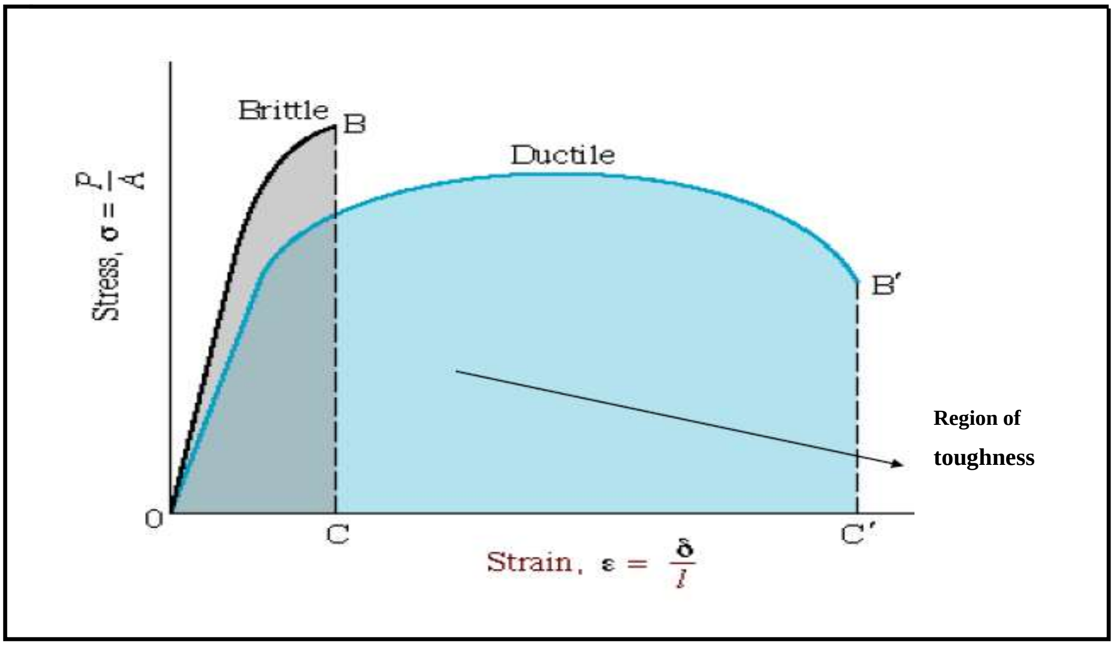


Figure 2.3: Comparison of ductile and brittle materials

Source: Sakran, S-*Materials Science: SSP 2412*

(iv) Elongation

Elongation is the increase in gauge length of a material under tension forces usually expressed as percentage of the original length, or expressed as the total elongation over a prescribed gauge length that extends across the fracture of a bar.

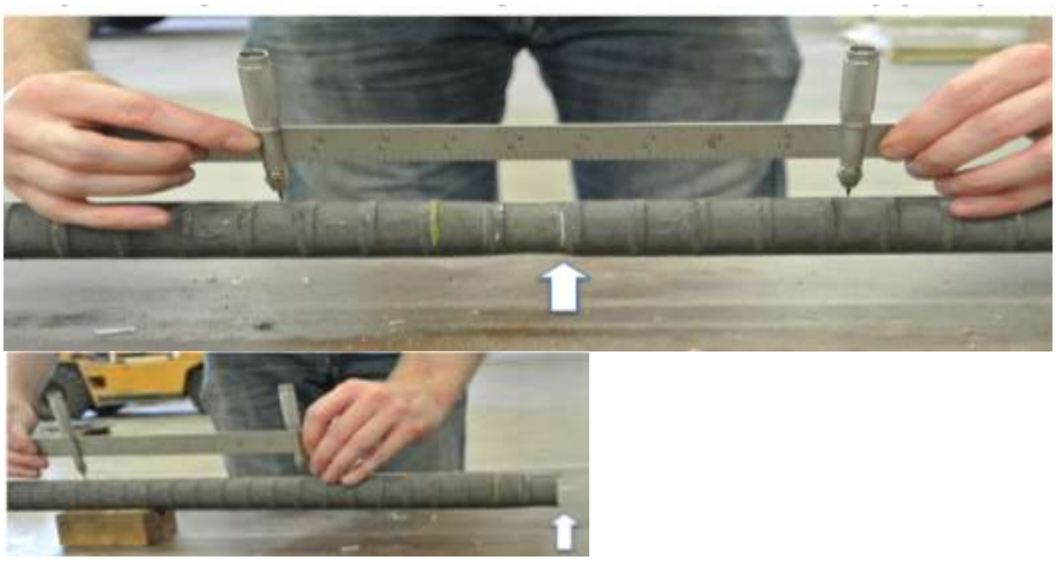


Plate 2.1: Steel bar elongation measurement procedure Source: NIST 2014

Uniform elongation (e_{u}) is the strain that occurs as the bar reaches its peak stress expressed as a percentage, it is the elongation at the maximum load, while total elongation (e_t) is the elongation of the original gauge length of specimen under tensile tension at fracture; this includes both uniform and non uniform elongation as shown in Figure 2.4. The Uniform Elongation provides a measure of the ability of the reinforcement to deform, both elastically and plastically, before reaching its maximum strength. It is a measure of the maximum amount by which a steel sample will stretch before it reaches maximum stress.

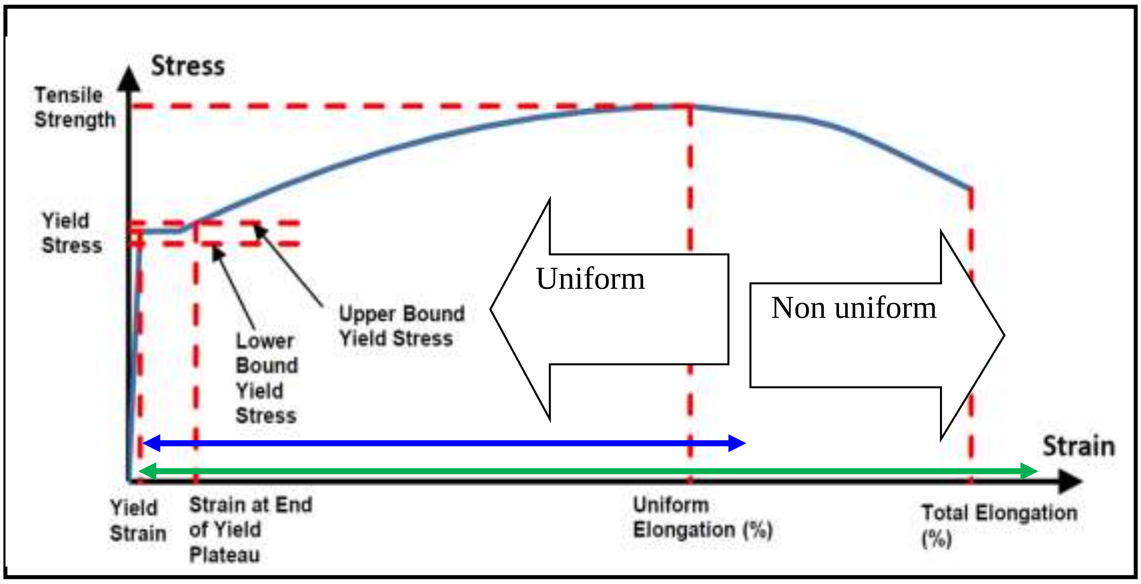


Figure 2.4: Idealized stress-strain curve with various tensile properties, Source: NIST, 2014

(v) Modula's of elasticity

Modulus's of elasticity also called Young Ṃodulus (Es or E) is a measure of the constant relationship between stress and strain up to the elastic limit. For all steel reinforcing bars, E is equal to 200,000 N/mm2. It is the slope of the stress-strain graph prior to yielding of the steel. It is expressed as ratio of stress force per unit area along an axis to strain ratio of deformation over initial length along that axis.

Rebars with appropriate chemical composition are generally said to exhibit very linear stress – strain relationship up to yield point.

It is ratio of stress to strain.

$$\cdot \varepsilon = \frac{\sigma}{E} = \frac{F}{E \cdot s} \quad \text{..(2.2)}$$

Where: $\mathcal{E}$ = Strain
ρ = Stress
E = Young modulus
F = Force

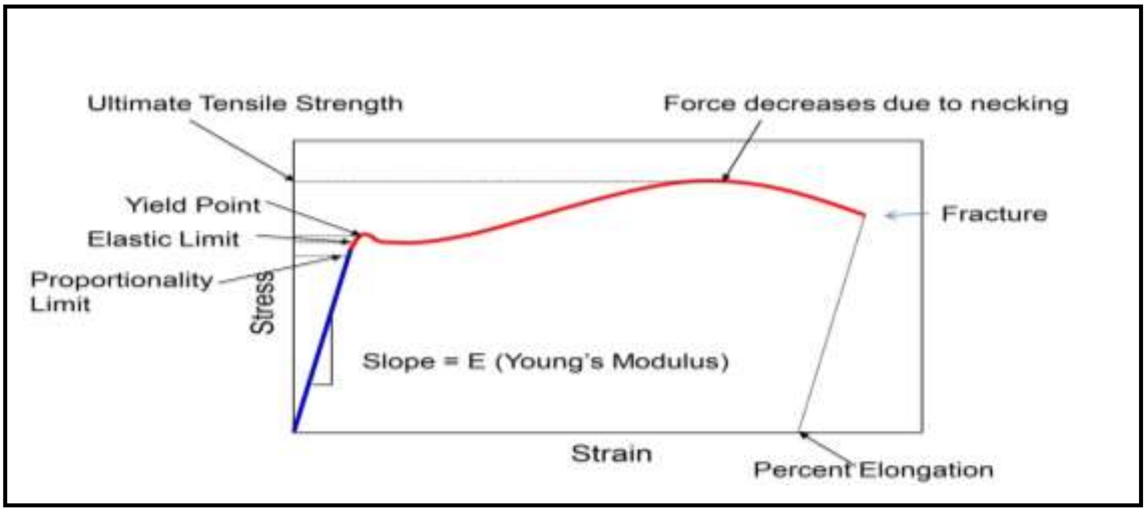


Figure 2.5: Stress–strain steel materials' young modulus of elasticity

Source: Sakran, S-*Materials Science: SSP 2412*

(vi) Passions ratio

Poisson's ratio is the ratio of transverse contraction strain to longitudinal extension strain in the direction of stretching force. The definition of Poisson's ratio contains a minus sign so that normal materials have a positive ratio, usually represented as a lower case Greek **V**

$$\nu = -\frac{\text{Strain in direction of load}}{\text{Strain at right angle to load}} \quad \text{.....................................(2.3)}$$

(vii) Bending properties

Most of reinforcing bars will require to be bent before being placed into concrete, however they may fracture on bending if radius of bend is too tight. BS 4449 (2009) specifies minimum mandrel diameters for bending test of high yield reinforcements. ASTM A615 (1979) specifies minimum mandrel diameters for bend test requirements. IS 1786 (2008) specifies maximum mandrel diameters for different grades and sizes, both standards ASTM A615 and IS 1786 considers size and grade. The bend and re-bend tests on steel reinforcing bars are two ways of evaluating ductility of reinforcement. The bend diameter varies with the bar diameter and in some codes varies with grade. The test specimen passes if no cracks appear on the outside of the bent portion of the bar (NIST, 2014). The method of testing is that the bar being tested is supported by two pins with a distance of three times the bar diameter plus the plunger. The force is applied through a plunger placed midway between the supports. The bar is then bent to an angle of 180^o.

2.3.3 Bonding Characteristics

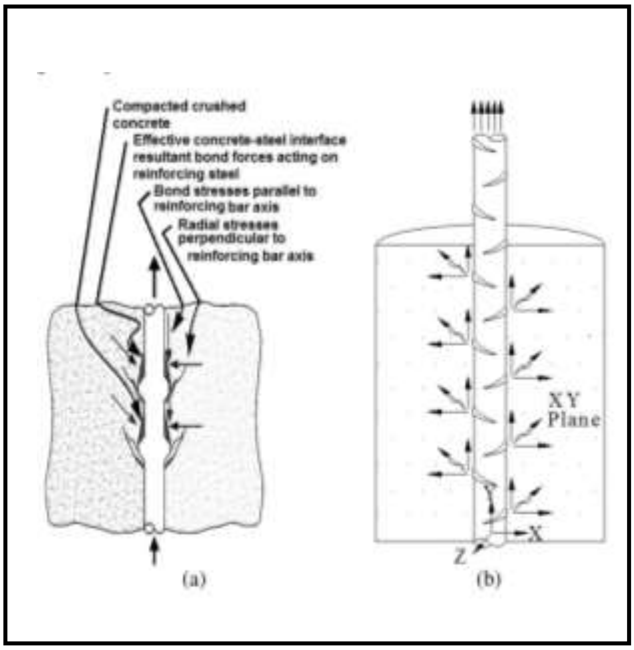
(i) Introduction

Bond in reinforced concrete refers to the resistance of surrounding concrete against pulling out of reinforcing bars. The bond between rebar and concrete depends upon many factors, such as size, bonding length, shape and geometry of ribs (Basu, 2004). Oluwafemi et al. (2018), evaluated surface geometries and physical properties of locally-rolled steel rods made from billets that are produced from locally-sourced scraps and three available imported rebars in Nigeria.

The results obtained were compared with specifications in NIS 117:2004 (local) and BS 4449:2005 and ISO 6935-2: 2007 (international) standards. Findings showed that none of brands fully conformed to the three standards in terms of diameter and cross-section area.

One of the fundamental assumptions of reinforced concrete design is that at the interface of the concrete and steel bars, perfect bonding exists. Based on this assumption, it follows that some form of bond stress exists at the contact surface between the concrete and steel bars**.** Bond strength results from several factors, such as adhesion between the concrete and steel interfaces and pressure of hardened concrete against the steel bars. In reinforced concrete beams, flexural compressive forces are resisted by concrete, while the flexural tensile forces are provided by reinforcements. For this process to exist, there must be force transfer, or bond between the two materials. For the bar to be in equilibrium, bond stresses donated as (f_b) must exist, if these disappear, the bar will pull out of the concrete and tensile force (T), will drop to zero, causing the beam to fail (Ghoneim & El-Mihilmy, 2008)

Whenever external load is applied on concrete, reinforcing bar receives part of the load through load transfer mechanism from concrete to steel. When tensile force is applied to the reinforcing bar, it develops stress components parallel and perpendicular to the contact surface as shown in Figure 2.6 (a) and (b) below. The stress parallel to the bar is termed bond stress. Radial stress generated perpendicular to contact surface is presented by shear stress in XY plane of concrete. Figure 2.6 (a) represents force components parallel and perpendicular to the steel concrete interface while (b) represents shear stress distribution in XX plane of concrete (Rashedul & Mashfiqul, 2014).



Fb = Fs = force in reinforcements then:

$$\boldsymbol{f}_{\mathbf{b}} = F_s/LP \longrightarrow \delta b = F_{s/Lx}\pi\Theta$$

$$F_{s} = L\,\pi\Theta \quad \ldots\ldots\ldots\ldots\ldots(2.4)$$

Where:

$\boldsymbol{f}_{b}$ =Anchorage bond stress.
Fb =Average bar force - L =Anchorage length
P =Nominal perimeter of the bar.

Figure 2.6: Bond force components acting in different directions

Source: Rashedul and Mashfiqul (2014)

2.3.4 Chemical Composition of Steel and its Influence on Quality

The selection of the correct chemical composition for any steel product is extremely important because it has remarkable effect on the final product. Steel is essentially an alloy of iron containing up to 1.5% carbon. The percentage composition of carbon between 0.05-1.5 percent plays a major role in steel classification (Kareem, 2009). The

Carbon Equivalence (CE), is regarded as a measure of the weldability of a steel, it is derived from a formula that allows for the influence of carbon, manganese, chromium, molybdenum, vanadium, nickel and copper (ARC, 2010). A study on variability of the chemical composition of reinforcing steel bars produced throughout Saudi Arabia that assessed quality of steel rebar was conducted by Salman and Djavanroodi (2018), results revealed that some compositions fall above the upper line of the control chart while less than 3% of the steel failed to meet minimum ASTM standards for chemical composition requirements. Different chemical ingredients in steel bars including impurities were highlighted and seem to serve different purposes in steel properties as tabulated in the Table 2.2.

Table 2.2: Influence of different chemical ingredients in rebar properties

Source: Salman and Djavanroodi, (2018)

No	Chemicals	Effect on re-bars	
		Property	Actual effect on the product
1	Carbon (C)	Hardness, strength, weldability and brittleness	Higher carbon contributes to the tensile strength of steel, that is, higher load bearing capacity and vice versa. Lower carbon content less than 0.1 % will reduce the strength. Higher carbon content of 0.3 % and above makes the steel bar un weldable and brittle.
2	Manganese (Mn)	Strength and yield strength	Higher manganese content in steel increases the tensile strength and also the carbon equivalent property.
3	Sulphur (S)	Present as an impurity which increases brittleness	Presence of sulphur should be limited as its presence in higher quantities makes the bar brittle during twisting and hot shot problem during rolling
4	Phosphorus(P)	It is an impurity that increases strength and brittleness.	Higher phosphorus content contributes to the increase in strength and corrosion resistance though brings brittleness resulting from formation of low euctoid phosphicles in the grain boundary.
5	Copper (Cu)	Strength and corrosion resistance	Being a pearlite stabilizer, it increases the strength and corrosion resistance property.
6	Chromium (Cr)	Weldability and corrosion resistance	Present as an impurity and influences carbon equivalent; weldability and increases corrosion resistance property.
7	Carbon equivalency (CE)	Hardness, tensile strength and weldability	This property is required to set the cooling parameters in TMT process and a slight variation in CE may alter the physical properties. In case of CTD bars, CE has a maximum limit of 0.42% though with no lower limit. Hence as long as chemical composition and physical properties of raw material are within specified limits.

2.3.5 Steel Reinforcing Bars Cost Analysis

According to Opeyemi et al. (2018) over 90% of storied buildings in Nigeria are made from reinforced concrete whose reinforcements are steel rebars. They are mainly designed based on the assumptions that they possess right nominal diameters and that they are of minimum yield strengths of 460 N/mm^2 as specified in different design standards, with specific ductility to prevent abrupt failures. If, however the rebars available in the market possess properties less than the assumed, then the consequences would be structural failures before their expected lifespan.

The 12 mm diameter bar was believed to be the most used steel bar diameter in construction industry, they were examined for: actual diameters; yield strengths; ultimate strengths; ultimate/yield strength ratio; ductility; and the cost of each brand against characteristic strength.

Findings revealed less conformity to standards in terms of diameter and yield strength as indicated on the Figures 2.7, 2.8 and 2.9.

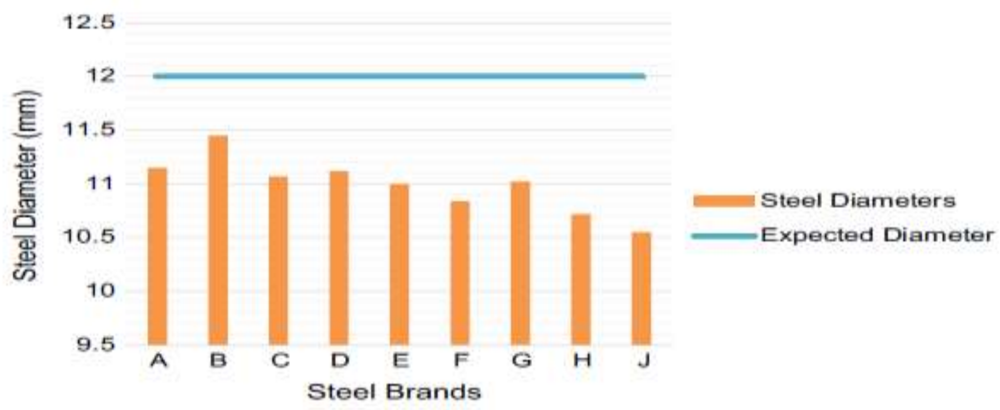


Figure 2.7: Steel reinforcing bars Diameter comparison

In the analysis and comparison of diameters, it was noted that none of the brands met the requirements. Diameters ranged from 10.5 to 11.5 mm diameter as opposed to 12 mm diameter as indicated by the blue line in Figure 2.7 above. On comparison of ultimate tensile strength and yield strength to BS 8110:1997 and BS 4449:1997 codes brands were analyzed and only three steel brands' yield strength conformed with BS 8110, while all brands' ultimate tensile strength met requirements of both codes as shown on Figure 2.8.

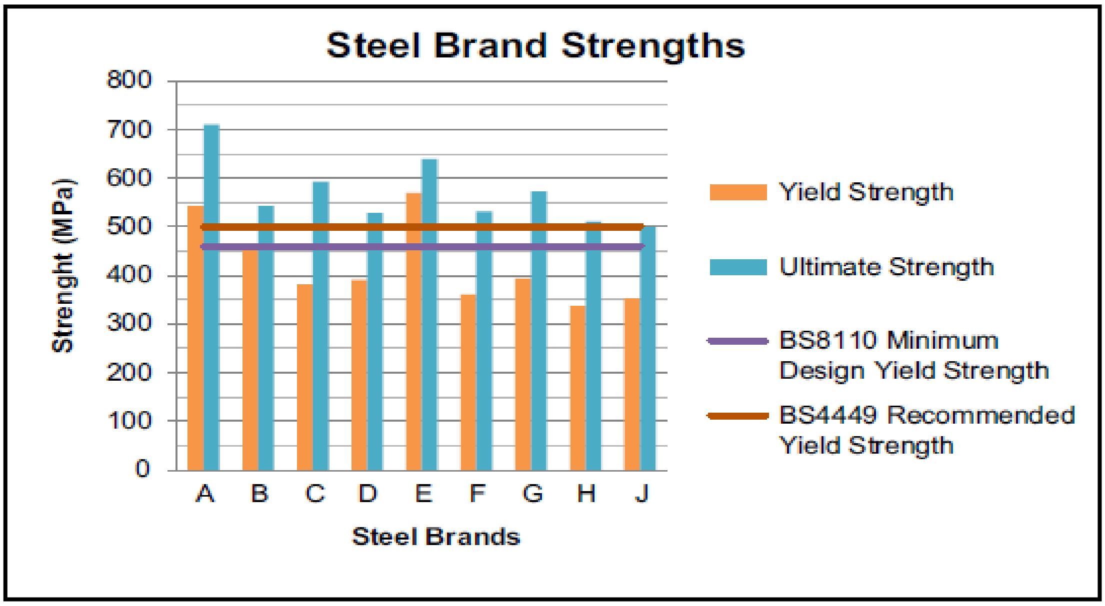


Figure 2.8: Steel reinforcing bars UTS and YS to BS 8110-1: 1997 and BS 4449-1997 comparison

Cost analysis was performed on the rebars to assess whether highest cost is justified by highest tensile strength. The assessment reveal that to some extent it is true as may be seem from Figure 2.9, brand A has the highest cost and has the highest tensile strength folowed by E in terms of cost which actually has the highest yield strength.

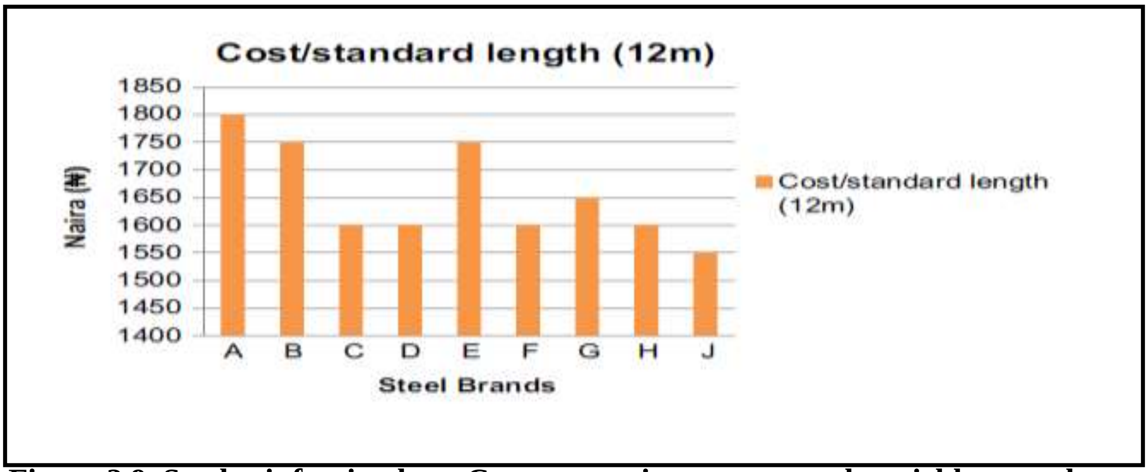


Figure 2.9. Steel reinforcing bars Cost comparison as opposed to yield strengths

Nkem et al. (2015) conducted investigated quality of steel reinforcing bars used in Lagos, Nigeria; 1325 samples of steel bars made of 10, 12, 16, 20 and 25 mm diameter were collected from building sites and tested. It was noted that most of Engineers were being forced to apply Fy = 410 N/mm^2 other than 460 N/mm^2 specified in BS 8110 which has become a common practice, the reason being rampant existence of substandard rebars in open market with lower characteristic strength than specified in standard codes. The parameters investigated include YS, UTS and Elongation which were calculated using below formulas.

$$\text{Yield Strength (N/mm}^2) = \frac{\text{Yield force}}{\text{Original cross sectional area}} \quad \ldots\ldots\ldots(2.5)$$

$$\text{Ultimate Tensile Strength (N/mm}^2) = \frac{\text{Maximum force specimen can withstand}}{\text{Original cross sectional area}} \quad \ldots\ldots..(2.6)$$

$$\text{Percentage Elongation (\%)} = \frac{\text{Final length} - \text{original length}}{\text{Original length}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.7)$$

2.3.6 Manufacturing Process and its Influence on Quality

Reinforcing steel bars may be rolled either from used scraps or defectives from different materials and plants or tested billets. Their manufacturing process have serious significant effect on their mechanical properties, UK CARES part 2 (2011) emphasizes on different process routes that produce different mechanical characteristics with quite diverse reactions to stress.

It also specifies two common steel making processes: The Basic Oxygen (BOS) and Electric Arc Furnace (EAF). In the basic oxygen process, pig iron is first produced by smelting iron ore then transferred to converter where approximately 30% of metal scrap may be added. Charges are then oxidized and impurities removed after which iron is refined into steel, steel produced normally have lower levels of sulphur, phosphorous and nitrogen. This process is generally used by large steel producing manufacturers. The second process of electric arc furnace involves almost 100% scrap metal which is used as a raw material with higher levels of residual impurities likes of copper, nickel and tin; this process is ideal for smaller scale steel making operations such as reinforcing steel bars.

In continuous casting process there are basically two processes employed for imparting strength to the steel reinforcing bars: The cold mechanical working that involves stretching and twisting of mild steel beyond its yield plateau into cold twisted deformed (CTD) bars. This method effectively results in an increased proof strength with a disadvantage however of reducation in ductility of the steel bar. The second method is thermo mechanical treatment (TMT) which is a heat treatment that is an advanced technique controlled by water quenching applied on the red-hot steel reinforcing bars as they come out of the rolling mill.

The process involves rapid quenching of hot bars through a series of water jets as bars come out of the last rolling mill stand. The strength of the bars is carefully controlled by optimizing the water pressure giving rise to an optimum combination of high strength, ductility and toughness with excellent bendability due to the unique feature of uniform elongation far better than conventional CTD bars (UK; CARES part 2, 2011).

Empirical studies have revealed that bars produced through conventional rolling in most of the developing countries, require further modification to have appropriate chemical composition to ensure that desired mechanical properties such as strength are obtained. Unfortunately, high costs involved have rendered the approach not easily adaptable by manufacturers. To meet an increasing global demand for reinforcing steel bars of high quality at a reasonably lower cost, appropriate production methods need to be developed (Singh & Kaushik, 2002).

A research was conducted on reinforcing steel bars by Mouradi, et al. (2014) as part of the experimental investigation to compare the tensile strength of rebars manufactured by two different processes of tempering and quenching. Results revealed that rebars manufactured by quenching process demonstrate higher values of yield strength as compared to its nominal values. It was expected that such comparatively high values of yield strength may have a considerable effect on the flexural behavior of beams as well.

2.4 Quality Assessment and Control

2.4.1 Introduction

Quality assessment is a method of assessing and evaluating the quality of materials gauged on a set of standards, this involves verification of samples (CIDB, 2015**)**. Government institutions and International organizations charged with standards have set different standards which are meant to be adopted for the safety of people and properties.

According to RS EAS 412-2: (2014) and BS 4449 (1997), requirements have been set of which the re-bars should meet in terms of physical features, mechanical properties and chemical composition. Although different countries might have set different surface marking standards, most of them have many features in common such as; bearing country of origin; name of manufacturer or rolling mill; steel grade; nominal length; nominal diameter and heat number. The manufacturer's product traceability tag should always be fixed on steel reinforcing bar bundle for the purpose of traceability whenever the need arises.

Quality control involves testing of units and determining if they are within the specifications for the final product stated in standards. The purpose of the testing is to determine any needs for corrective actions in both manufacturing process and post manufacturing. Quality control takes different dimensions and should start before production. For effective quality control, a permanent system of routine inspection that involves sampling, testing and evaluation of results to ensure required parameters are met and then results recorded and properly documented. Quality of the raw material need to be controlled before steel making by proper sorting to ensure right contents of ingredients.

2.4.2 Quality Control before Manufacturing

Modern steel making process control demands accurate information regarding the quality of all feed such as scrap, hence sampling and testing techniques such must be established to ensure quality and consistency of carbon better quality of steel.

In USA the institute of scrap iron and steel have been put in place and has identified 29 different types of scrap while in Europe a committee of national scrap federations and association of the common market have been instituted and mandated to control the quality of scraps in steel making (Singh & Kaushik, 2002).

Unfortunately, in India, in the absence such control mechanism, any type of scrap is being used as feed stock with varying chemical percentage of elements that results into undesirable end products.

Hence, since use of scrap in steel making is inevitable, the systems maximize degree of control on the type of scraps used for better products (Singh & Kaushik, 2002).

2.4.3 Quality Control During Manufacturing

During production careful measures should be taken that ensure quality production, like in Thermo Mechanical Treatment (TMT) process which is commonly being used now days, requires a considerable care to be exercised during rapid water quenching of hot bars through a series of water jets, as bars come out of the last rolling mill as any slight mistake would lead to substandard steel reinforcing bars (UK CARES part 2, 2011).

2.4.4 Post Production Quality Control (identification and traceability)

In addition to quality control during selection of law materials and during production, traceability also forms part of quality control. MMFX STEEL Corporation (2011) of America has introduced quality control systems where all product mill labels are checked against the qualified supplier’s chemistry record for heat number and are to include: point of origin, production date, product size, type, grade, length weight, heat and roll numbers. The mill certification is kept in the file after it has been checked against the mill tags. In this way their products can be well traced through mill tag, a combination of a unique heat and roll numbers are sufficient to trace the finished product back to relevant quality records. Heat number is a unique fingerprint which identifies the chemical composition of the product; the date the heat was melted and chemical composition certification.

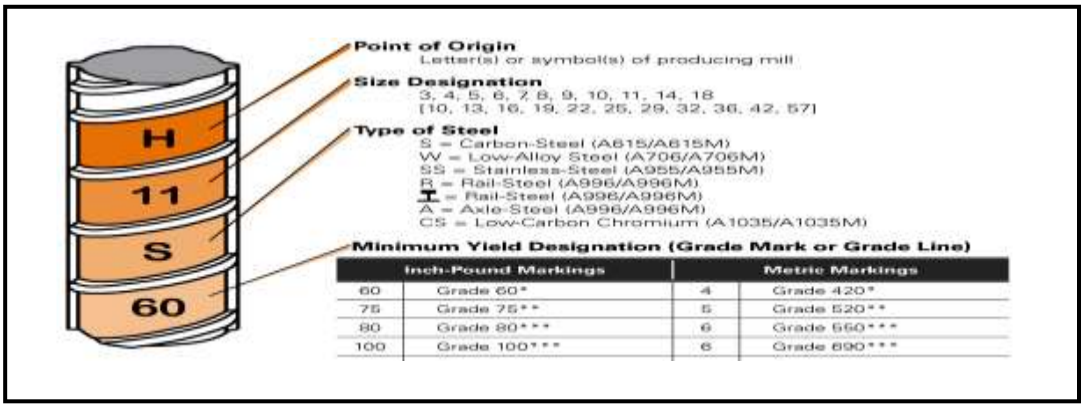
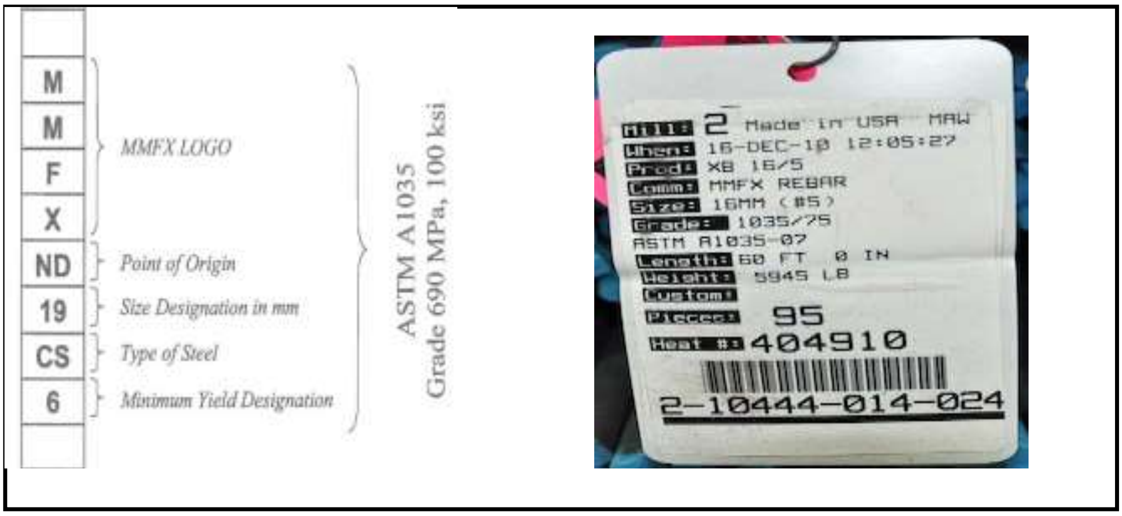


Figure 2.10: Standard rebars' marking sample

Source: Concrete reinforcing steel Institute (CRSI)



(a) S*teel labeling sample* *(b)* typical mill label/tag on specific heat N^o

Figure 2.11. MMFX corporation steel labeling and tag

Source: MMFX steel corporation of America, (2011).

The Government of Hong Kong (GoHK) has developed means of quality control, which involves traceability of products, where each delivered batch is identifiable and traceable to the manufacturer and to its production data. Such production data includes country of origin, name of the quality assurance manufacturer, standard of compliance, steel grade, nominal length, nominal diameter and heat/cast number of the steel reinforcing bars. The manufacturer's product traceability tag affixed on a steel reinforcing bar bundle is one of the acceptable measures to prove its traceability (GoH K, 2012).

Adetoro et al. (2017), in the assessment of suitability of selected reinforcing bars used in construction industry in Nigeria observed that none of the reinforcing bars found in the market had neither batch reference, identification mark or name of manufacturers. It was even doubtful if laboratory tests were carried out on these bars to ascertain their level of compliance with the national standards' strength requirements. It was concluded that the level of quality control in the manufacture of reinforcing bars could not be ascertained. The disparity in measured and nominal sizes of some samples, made the quality control of the local bars doubtful.

Due to an increasing incident of collapse of reinforced concrete buildings, and belief that little research has focused on reinforcing steel bars most likely due to assumption that they are manufactured in the controlled environment, imported rebars had been preferred for many years due to lack of confidence in the locally made rebars.

A research was conducted on diameter inconsistency, strength and corrosion characteristics of locally produced and imported steel reinforcing bars in Ilorin, Nigeria; the research which compared locally made and imported rebars. Results confirmed substandard locally made rebars deviated more from designated diameters; equally the strength was lower as compared to imported rebars.

It was concluded that quality control of locally made rebars right from manufacturing mills was undermined (Bamigboye et al., 2017). Investigation on quality of steel reinforcement bars was conducted by Taghried et al. (2017), in Khartoum state using three standards: the British, American, and Sudanese standard specifications. Samples were taken from seven factories; it was observed that two samples out of seven did not meet nominal diameter standard requirements. For tensile/yield strength ratio only one sample failed to meet American standard. It was observed that at no single point did all sample meet all investigated parameters for all three baseline standards.

2.5 International Standards

2.5.1 Introduction

International standards are developed by international organization (International Organization for Standardization –ISO) for consideration and use worldwide. They may be used either by direct application or by a process of modifying an international standard to suit local conditions. The adoption of international standards results in the creation of equivalent national standards that are substantially the same as international standards in technical content. They help to harmonize technical specifications of products and services making industry more efficient and breaking down barriers to international trade. Adherence to it helps reassure consumers that products are safe, efficient and good for the environment (ISO 6935-2, 2015). As regards steel reinforcing bars quality based properties have been standardised by different organisations such as British standard (BS) which we have adopted in Rwanda.

2.5.2 British Standards

This British Standard BS 4449:1997 covers plain round steel bars in grade 250, and deformed (type 1 and 2) high yield steel bars in grade 460, the latter in two ductility categories, 460A and 460B. It has set a number of parameters with permissible deviations from the nominal physical, mechanical and chemical composition requirements. BS 4449: 1997, Table 4 indicates chemical composition of steel grades in cast analysis, while Table 5 gives maximum carbon equivalent (C_{eq}) values for product analysis as 0. 51 while BS 4449: 2005 and 2009 puts the value at 0.52; which is the same value as for Hong Kong construction standard (CS2: 2018). The Indian standard (IS 2008) sets carbon equivalent (CE) at 0.53, Australian/New Zealand Standard (AS/NZS 4671:2001) sets carbon equivalent (Ceq) in the range 0.44 and 0.46 depending on ductility.

The BS 4449 (2005) updated to 2009 made a full revision of BS 4449: 1997 and defines three grades of reinforcements all of 500 MPa characteristic yield strength but with different ductility characteristics which are B500A, B500B and B500C. The characteristic yield strength has been increased from 460 to 500 N/mm2 as tableted in Table 4. BS 4449: (2009), while Table 10 specifies absolute minimum and maximum values of tensile properties where yield strength minimum value have been put at 485 N/mm^2 and maximum value as 650 N/mm^2. The important modification is the maximum and minimum values of characteristic yield strength of rebars which are very important. Equally Hong Kong construction standard-GoHK, (2018) Table 8 gives absolute minimum and maximum values of tensile properties as those in BS 4449 (2009) Table 10 with the addition of grade 250 which has a minimum value of 243 N/mm^2 with no maximum value.

Madias et al. (2017), in the analysis of international standards on steel reinforcing bars basically on quality constraints reviewed mechanical properties, bending and re-bending, and chemical composition plus other parameters of interest like traceability. They emphasized on the fact that standards usually come into effect with a certain delay as opposed to the advances in technology in product manufacturing based on the growing requisites of the users. They noticed the trend to improvise high yield grades beyond 500 N/mm^2, with aim of decreasing steel reinforcing bars congestion, specifically in column - beam crossings in high-rise buildings for seismic zones.

The findings of the study are shown in Figure 2.12.

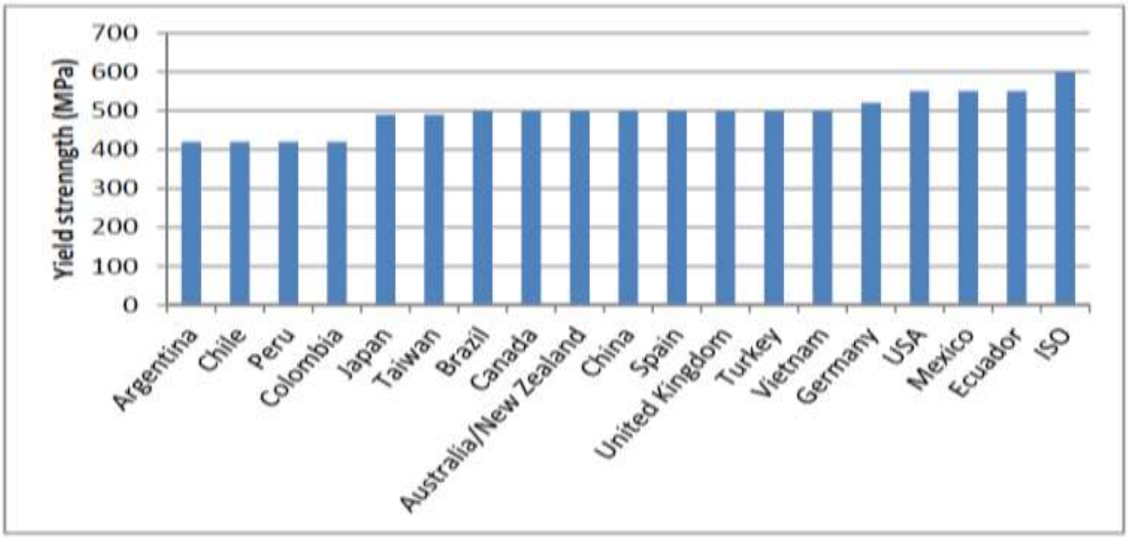


Figure 2.12: Minimum YS for HYS rebars for the selected codes

Source: Madias et al. (2017)

The department of Building and Housing. New Zealand (2005) report on grade 500E reinforcing steel bars puts much emphasis on steel bar features that should be identified by different users. The report focuses on designers, fabricators and contractors to check origin of steel bars which can only be obtained from mill and importation certificates even though the information does not guarantee compliance hence need for further laboratory examination before use.

2.6 RC Beam Flexural Performance Behavior

2.6.1 Introduction

Reinforced concrete (RC) beam as a part of building structural element is designed to sustain flexural and shear loading. Chanakya, (2009) defines flexural strength as maximum stress at the outmost fiber on either the compression or tension side of the structural member under flexural force. The normal procedure for testing flexural strength is that the specimen is laid horizontally over two points of contact and then a force is applied to the top of the sample through either one or two points of contact until the sample fails.

The maximum recorded force is the flexural strength of that particular sample. It is important that the structural engineers be able to predict the ultimate strength of a structural member with satisfactory accuracy; equally important is also to understand the un proportionality of stress and strain at that point. The two most common types of flexure test are three point and four point flexure bending tests. A three point bend test consists of the sample placed horizontally upon two points and the force applied to the top of the sample through a single point which results into the sample bending into the V shape, while a four point bend test is force applied through two points and consequently the sample experiences contact at four different points resulting into U shape bend. Two options are shown in the two respective Figures 2.13 (a and b).

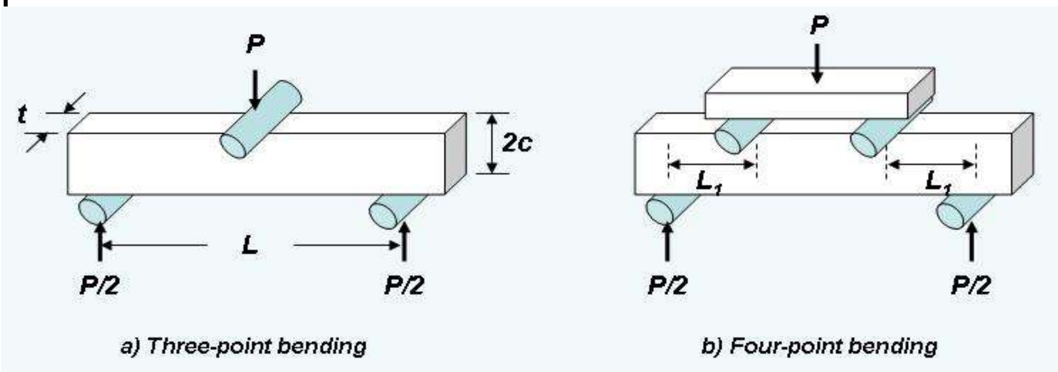


Figure 2.13: Two common types of flexural test set up

Source: Farrukh and Mohd, (2011)

When a specimen is placed under flexural loading all three fundamental stresses of the tensile, compressive and shear develop as shown in Figure 2.14 and so the flexural properties of a specimen are the result of the combined effect of all three stresses together with rate of loading and geometry of the specimen to lesser extent.

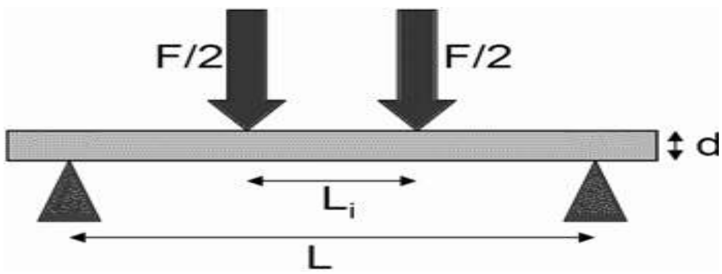


Figure 2.14: Four point loading with resulting stresses

Source: Libor et al (2012)

From the applied forces. shear and bending moment diagrams are obtained which are analytical tools used together with structural analysis in the structural design by determining the shear force and bending moment values at a given point of structural element while under loading.

2.6.2 Flexural Design of Reinforced Concrete Beams

Just like other structural members, reinforced concrete beams analysis and design involves selecting of an appropriate material and determining of member dimensions ensuring that design strength is equal or less than the required strength. Three major parameters of safety, internal strength and deflection are always investigated to ensure applicability and suitability. To achieve the above requirements, BS 8110 part 1 (1997) bases its design on limit state philosophy with aim of achieving acceptable probability that the structure being designed does not become unfit for its intended purpose during its lifespan. The philosophy of limit state is divided into ultimate limit state (UTS) and serviceability limit state (SLS). The design ensures that ultimate limit state is not reached and then checked for serviceability limit state is satisfaction. When UTS is reached then the member fails hence need to examine all factors that may lead to this situation such as: bending, shear, compression and tension forces and then possibility of overturning. Equally controlled is SLS through member deflection by ensuring appropriate basic span depth ratio; cracking by ensuring appropriate steel area and ratio (Draycott, 1999). The design approach as specified in various codes suggests that the reinforced concrete beam be designed to fail in a ductile manner (Stefanus et al., 2017). In flexural design of reinforced concrete beams different parameters are put into consideration such as:

(i) Ultimate design loads (W) = (1.4 G_k +1.6Q_k) x L (effective span) ,……… (2.8)

(ii) Characteristic strength of materials, mainly concrete and rebars, f_{cu} and f_y respectively.

(iii) Partial safety factor of materials(Υ): BS 8110 part 1 1997 specifies 1.15 for reinforcement (Υ_y) and 1.5 for concrete in flexure(f_{cu}) specifically during ultimate limit state,

(iv) Ultimate design strength of materials (UDS): characteristic strength / Υ

- UDS for concrete = $f_{cu}/\ \Upsilon_m = f_{cu}/1.5 \quad = 0.67f_{cu}$…………..(2.9)
- UDS for steel reinforcing bar = $f_y/\ \Upsilon_m = f_y/\ 1.15 = 0.87\ f_y$………(2.10)

(v) Design moment (M) = $WL^2/8$ ……………………………………..(2.11)

Design moment (M) may be obtained from bending moment diagrams or from the standard formulae == $0.156f_{cu}bd^2$……………………………… (2.12)

(vi) Flexural strength (N/mm2) = Fl/bd^2 ……………………………….(2.13)

Where F is ultimate load, l is effective length, b is the beam width and d is the effective depth.

(vii) $A_s = M / 0.87f_y Z$ ………………………………………………(2.14)

(viii) Z= d-0.9x/2 ……………………………………………………(2.15)

In order to ensure that the member is under reinforced, BS 8110 Part1 1997 limits of neutral (x) at maximum depth of 0.5d hence X≤ 0,5d. it also limits main tension reinforcements of high yield steel (460 f_y) at an area of 13% of total concrete area. The general theory for ultimate flexural strength design takes the assumptions stipulated in BS 8110: 1997, section 3.44**.**

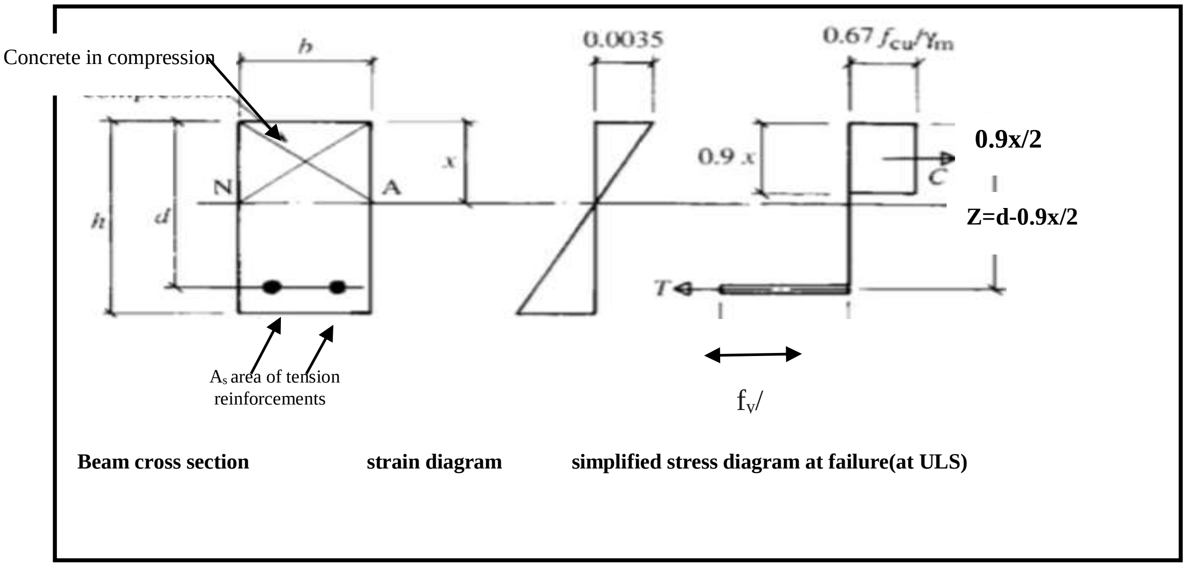


Figure 2.15: Reinforced concrete beam Stress- strain block

Source: Draycott, (1999)

2.6.3 Reinforced Concrete Flexural Testing

Flexural testing is performed to measure flexural strength and flexural modulus, the two values that are used to measure structural members' ability to withstand the bending forces. The flexural strength represents the highest stresses that are experienced within a structural member at the point of yield, hence effective way of assessing whether a member can stand the applied flexural forces. Kumar and Karthik (2017), had experimental study on flexural behavior of beams reinforced with GFRP rebars using two point loading test and clearly observed an increase in the ultimate load value that is directly proportional to ultimate loads for beams as shown in Table 2.3.

Table 2.3: RC beam flexural behavior results with varying steel ratio

Source: Kumar and Karthik (2017)

		Ultimate Load (kN)		**Beam size**
Sn	Reinforcement ratio	RC beam with Steel	RC Beam with GFRP	
1	1	88.5	126	W= 100 mm
2	1.5	124.3	74.8	D= 200 mm
3	2.5	162.9	48	L= 1200 mm

Kulkarni et al. (2012) in the analysis of the behavior of simply supported reinforced concrete beam subjected to gradual increasing loading, observed two phases of initial uncracked and ultimate condition at collapse.

In the first phase of un-cracked phase, moment (M) was less than cracking moment (Mcr) and the maximum tensile stress in the concrete was less than its flexural tensile strength consequently entire section was effective in resisting the moment. The uncracked phase reached its limit when M = Mcr. As loads increase strain in tension steel increases which results in an upward shift of the neutral axis with ultimate increase in deflection and finally the beam completely fails.

Kesegić et la. (2009) observed the compression mode failure of reinforced concrete beams in which concrete crushes before steel yields. Such a beam is said to be over-reinforced where concrete reaches ultimate stress before steel reaches its yield stress.

An experimental study on RC beam flexural was conducted by Balamurugan et al. (2017) to investigate its behavior by varying aggregate in tension zone. The study aimed at reducing self weight of beams, monitor its load deflection behavior and assess its load carrying capacity and flexural strength. Beams were simply supported and tested under two point loading. Results are indicated in Table 2.4

Table 2.4: Flexural experimental results with varying f_{cu} in different beam zones

Source: Balamurugan et al. (2017)

Beam Description	Beam identification	Beam size (mm)	Rebars	Yield deflection (mm)	Ultimate deflection (mm)	Pcr (KN)	Pu (KN)
Solid beam	RC-SB	W =150	As = 3 Y 12	3.6	7.5	79	112.2
Sandwiched beam	RC-LB	D= 200 L=1500	As' = 2 Y8	6.2	12.4	82	106.6

An investigation was conducted by Brindah and Nagana (2010) on flexural strength of beams incorporating copper slag as partial replacement of fine aggregate in concrete, different concrete mixes were prepared with different proportions of copper slag as replacement of fine aggregates, percentages of coper slag ranged from 0% (control beams) to 50% details of beams and results are presented in table 2.5 below.

Table 2.5: RC beam flexural experimental results with replacement of aggregates
Source: Brindah and Nagana (2010)

Beams materials and size	Beams Description	Fine aggregate replacement	Average ultimate load (tones)	Flexural strength (N/mm2) *PL/BD²*
Mix ratio= 1: 1.38: 3.23; Beam size (mm) W = 150 D= 150 L = 1000 Rebars As = 2Y12 As' = 2 Y10 W/C 0.5	Control beams (A1 to A3)	A - 0% replacement	12 (117.6 KN)	35.56
	Bs	B- 20% replacement	16.72	48.53
	Cs	C- 30% replacement	17.24	51.08
	Ds	D- 40% replacement	17.81	52.77
	Es	E- 50% replacement	17.61	52.18

It was concluded that the addition of copper slag has improved the compressive strength, split tensile strength and flexural strength of concrete and the flexural strength of beams increases by 30% for 40% replacement of copper slag.

2.6.4 Ductility in Reinforced Concrete Beams

Alhassa et la. (2017) describes ductility as a structural property that shows the ability of the structural member to undergo large deflections prior to failure. While Kumaraswamy (2013) describes ductility of a beam as its ability to sustain deformation beyond the elastic limit as it maintains the reasonable load carrying capacity until total failure occurs.

Kwan et al. (2015) investigated the effects of concrete grade and steel yield strength on flexural ductility of reinforced concrete beams. The study revealed that at a fixed degree of the beam section in either status whether under or over reinforced, the flexural ductility decreases slightly with the tension steel yield strength as well as the concrete strength but increases slightly with the compression steel yield strength.

It was also observed that the use of a higher concrete strength increases either the flexural strength or the flexural ductility or both hence achieving flexural strength and flexural ductility simultaneously. It was concluded that at a given flexural strength, a higher tension steel yield strength results into lower flexural ductility while higher compression steel yield strength would lead to higher flexural ductility.

Kwan et al. (2002) in the study of flexural strength and ductility of reinforced concrete beams cited the need to consider both flexural strength and ductility by keeping the beam under-reinforced for the purpose of the structural safety while emphasizing the importance of ductility which is at least as important as strength. A good ductility would provide the beam with a much better chance of survival when it is overloaded, it was noticed that the use of a higher grade concrete could increase both flexural strength and ductility. However, the addition of compression reinforcement without increasing the tension reinforcement could produce significant increase in flexural ductility with little increase in flexural strength, whereas the addition of compression reinforcement together with an increase in tension reinforcement could increase both the flexural strength and ductility. The ductility of a flexural member can be obtained from its load deflection curve as ratio of ultimate deflection to the deflection at first yield is known as ductility factor.

$$\text{Ductility factor} = \frac{\text{Ultimate deflection}}{\text{Deflection at first yield}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.16)$$

In order to ensure ductility in RC beams, they should be designed in a way that depth of neutral axis does not exceed the limit, a situation where tension reinforcements yields before concrete crushes which is the under reinforced concrete (Hong Kong institute of vocation education, 2014)

Abdelhamid et al. (2016) in the assessment of flexural behavior of beams reinforced with steel bars exceeding the nominal yield strength asserts that much attention has been given to the effect of the variability of concrete and less effort if any has been put on effects of variability of steel strength, which may be a result of assumption that steel manufactures are always complying with minimum code specifications. Steel mechanical properties have more often exceeded the minimum nominal strength values for a specific grade of steel. Consequences have been unexpectedly high values of steel yield stress that reduce the beam ductility. Appropriate design corrections were proposed to account for high yield stress values in order to achieve the desired ductility of beams while maintaining the moment capacities.

Balamoorthi et al. (2017) investigated flexural behavior of reinforced concrete beam by varying the grade of concrete in tension zone. Aim of the study was to find ways of reducing material cost of the structure without losing its strength. Lower grade concrete in different mix ratios was placed below neutral axis (in tension zone) since concrete serves no purpose in tension only to transfer strain from steel to steel which is sacrificial.

$$\text{Neutral axis } (X_u) = \frac{0.87 \times F_y \times A_{st}}{0.36 \times F_{ck} \times b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.17)$$

Results reveal that: solid beam Pcr = 79 KN with Pu of 112.2KN while beam with low grade concrete below NA had Pcr of 81.4KN with Pu of 108.6 KN.

It should be noted that flexural behaviour was similar for beams with lower grade beam performing slightly better for 1st crack load while solid beam also slightly higher for ultimate load.

Kumar and Rajkumar (2016) carried out an experimental investigation on the flexural behavior of concrete beams reinforced with glass fiber reinforced polymers (GFRP) bars, with control beams of different concrete grades. In order to observe the ductility and strength performance on reinforced concrete beam results as shown in Table 2.6.

Table 2.6: RC beam flexural behavior results with varying concrete strengths

Source: Kumar and Rajkumar (2016)

Beam components	**Concrete Grade**	**1st Cracking Load (kN)**	**Ultimate Load (kN)**
-Top – Reinf: 2 of 8 mm Θ steel, -Bottom – Reinf: 2 of 10 Θ mm steel. -Stirrups of 6 mm Θ @ 130 mm: -Fy 415	M30	32	95
-Top – Reinf: 2 of 8 mm Θ steel, -Bottom – Reinf: 2 of 10 Θ mm steel. -Stirrups of 6 mm Θ @ 130 mm -Fy 415	M40	*34*	*108*

It was observed that load for the 1st crack is related to concrete tensile strength which in turn is a function of compressive strength, hence increasing the concrete compressive strength is expected to yield higher cracking loads.

Mita and Sunitha (2016) in the experimental analysis of flexural behavior and crack pattern of RCC composite beam, beams were designed as under reinforced according to IS 456-2000. The reinforcement for the beam specimens were 2 of 12 mm diameter at tension zone and 2 bars of 10 mm diameter. The shear reinforcement provided for three beams are of 10mm dia. stirrups at 150 mm spacing.

2.6.5 Factors Affecting Flexural Strength

Many factors have been found to have influence on the flexural tensile strength of concrete in different researches. According to Mohd et al. (2014), stress level, size, age and confinement to concrete flexure member have a larger influence on flexural tensile strength. Equally deflection and cracking behavior of concrete structure depend on the flexural tensile strength of concrete. Confining reinforcements have been proved to increase ductility. Therefore, the effect of the factors like level of stress, age and confinement of concrete member should be given priority while studying the flexure tensile strength of concrete member.

Russell and Asamoah (2016) in the evaluation of flexural strength of reinforced concrete beams made from phyllite aggregates, observed that flexural strength of a member was based on satisfaction of applicable conditions of equilibrium and compatibility of strains in longitudinal reinforcement and the concrete. The RC beam may be over-reinforced in which there are more longitudinal reinforcement than required to create the balanced state, a beam may also have less longitudinal steel bars than required in a balanced situation, in this case steel reaches its yield point before the concrete reaches its ultimate strain of 0.0035 in BS and 0.003 in ACI, this is called under-reinforced situation which is more preferred than the former as it gives more ample time in case of structure failure.

The deflection of two reinforced concrete beams under increment of flexural loading presented in Figures 2.16 (a and b) below suggest that both RC beams generally have a similar behavior initially as deflection is proportional to the applied load which is elastic behavior in the pre-cracked region, after the 1st crack the steel reinforcements take over the load resistance and the flexural stiffness of the two beams behaves differently as they depend on steel strength.

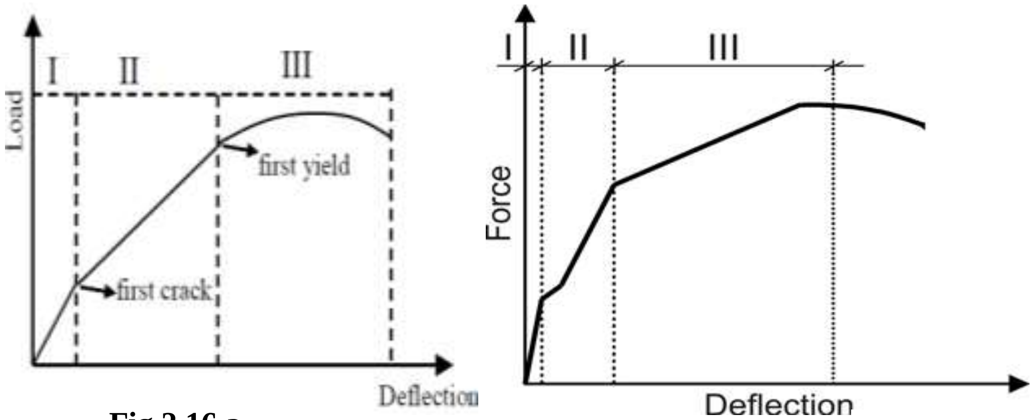


Fig 2.16 a

Fig 2.16 b

Figure 2.16: RC beam load-deflection curve behavior

source: *Stefanus* et al. *(2017) Kesegić et al. (2009)*

Stefanus et al (2017) in the study of RC Concrete beam flexural loading, three regions were established; the pre-cracking region which is fully linearly elastic with zero load; second area which is post-cracking region where reinforced concrete beam cracks simultaneously at various points depending on the loading intensity up to the first yield of the reinforcement and third region where the beam behaves non-linearly.

Kesegić et al. (2009) describes the three zones shown in the Figure 2.16 obtained in the experimental investigation as: Zone I that represents a situation before appearance of the first crack where reinforced concrete member behaves elastically; Zone II represents a situation after appearance of the first crack where actually reinforced concrete beam has cracked but before the steel yields, a situation where a member may not be fully cracked while Zone III represents a situation after the steel yields, at this point neutral axis shifts to the compressive edge.

Tejaswi and Eeshwar (2015), in the analysis of the flexural behavior of reinforced concrete beams with classifications of under, balanced and over reinforced sections, experiment was conducted with three point loading method and flexural behavior was slowly observed. The data in the Table 2.7 indicates beams and subsequent results:

Mix ratio = 1: 1.34: 2.88; W/C= 0.41, F_{ck} = 38.24 N/mm^2, F_y = 415 N/mm^2, Ast = area of steel bars in the beam, while the size of the beam = 1200 x200 x100 mm.

Table 2.7: RC beam analysis in under, balanced over reinforcement modes

Source: Tejaswi and Eeshwar (2015)

Name of	**Ast**	**1st crack**	**Ultimate load**		**Design load**
Section	mm2	KN	FEA	Exper	KN
Under	226.2	30	75.1	73.3	70.4
Balanced	326.1	34	78.4	88.8	91.5
Over	402.6	36	80.4	86.2	103.5
Plane		11	11.2	10.31	

In comparison of three types of beams, it was observed that deflection is higher in over reinforced beams followed by balanced and least being under reinforced, the same order is observed on subsequent 1st crack and ultimate loads and contrary to the stress in steel which is in reverse order, consequently under reinforced beam reaches ultimate stress of 415 N/mm^2 while over reinforced reaches 87%of the ultimate stress.

2.6.6 Modes of Reinforced Concrete Beam Failure

Eskenati and Varasteh (2015) in the investigation of premature failure and its prevention in flexural beams, identified flexural and shear modes of failure as main two basic modes in which reinforced concrete beams may fail. While flexural mode of failure is ductile, the shear mode failure is so sudden hence brittle in nature. It is suggested that reinforced concrete beams must be designed to ensure ductile flexural mode of failure. Carpinteri et al. (2011) in the assessment of transition between different failure modes of reinforced concrete beams noticed three fundamental failure mechanisms which are: flexural where steel yields; shear in which case there is diagonal crack within concrete crushes and finally concrete crushes.

Whenever a simply supported beam is designed to fail by flexure mode, in the process of failing cracks start to appear in the middle third of beam at point of high moments. At this particular point, loading will have exceeded the flexural strength of concrete. After that, the tensile reinforcement takes over from concrete to carry the imposed loads after which steel starts yield, consequently concrete starts crushing and spalling of concrete cover. Higher shear stresses develop and any slight increase in loads result into the disintegration of the compressed concrete and finally total failure.

2.6.7 Research Review

Steel reinforcing bars are still main construction materials, more so in developing countries where most of buildings and other civil engineering structures are of reinforced concrete mainly with rebars that serve as backbones.

The quality of steel reinforcing bars are particularly important as they govern the stability and strength of reinforced concrete structures, therefore knowledge on quality status can serve as a mitigation measure in formulating control mechanisms.

It has been observed that assumed high yield steel bars with 460 N/mm^2 found on local market are actual mild steel bars of 250 N/mm^2. It has also been revealed that different countries have established different quality control measures. It is also now clear that milling steel bars from scraps is almost inevitable, hence need to put in place scrap quality control methods from pre-production, production and finally during post production through traceability and testing of materials before being put into use.

2.6.8 Research Gap

Quite a number of researches have been conducted on quality of steel reinforcing bar available in East African countries with major focus on steel reinforcing bars milled from scraps and sometimes results have been contradicting. Unfortunately, only one related research has been conducted by Munyazikwiye (2010), on quality of rebars available in Rwanda in which like many others concentrated on steel reinforcing bars milled from scraps. However, according to CARES part 3(2011), manufacturing re-bars from scraps is almost inevitable and good quality rebars with sound and desirable properties have been milled from scrapes, hence problem not being scrapes but rather type of scraps which requires scrutiny of highest level.

Actually, very little research has been done on the quality status of steel reinforcing bars available in Rwanda and their structural performance in structural elements.

2.6.9 Research Variables

The scope of investigation on quality of steel reinforcing bars available in Rwanda and their subsequent reinforced concrete beams' performance behavior were restricted to few areas in order to reduce number of variables low enough so as to achieve detailed and definitive conclusions. The study involved both independent and dependent variables as illustrated in the conceptual framework below:

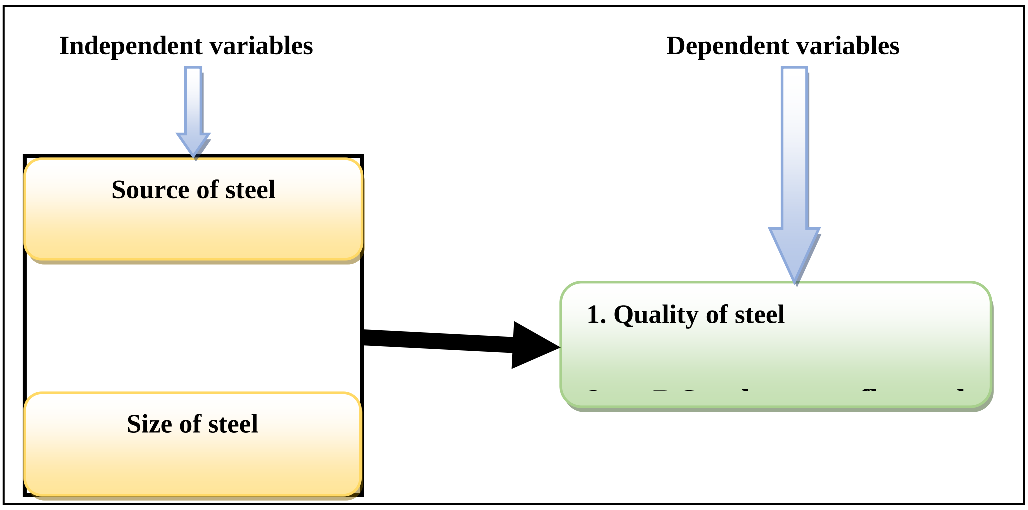


Figure 2.17: Conceptual Framework

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter presents materials and methods used in this study to investigate the quality of steel reinforcing bars available in Rwanda and their performance in structural elements. It illustrates approach to the research giving a step by step procedure of the work involved right from selection of samples, preparation of specimens for testing and finally testing. While reinforced concrete beam structural performance, compressive tests and bonding properties together with some steel bar tensile tests were conducted at material and structural laboratory at Jomo Kenyatta University of Agriculture and Technology (JKUAT), other tests that could not be performed at JKUAT laboratory such as chemical composition analysis were conducted in STEELRWA, a steel rolling mill in Rwanda and Rwanda Standards Board (RSB) laboratories.

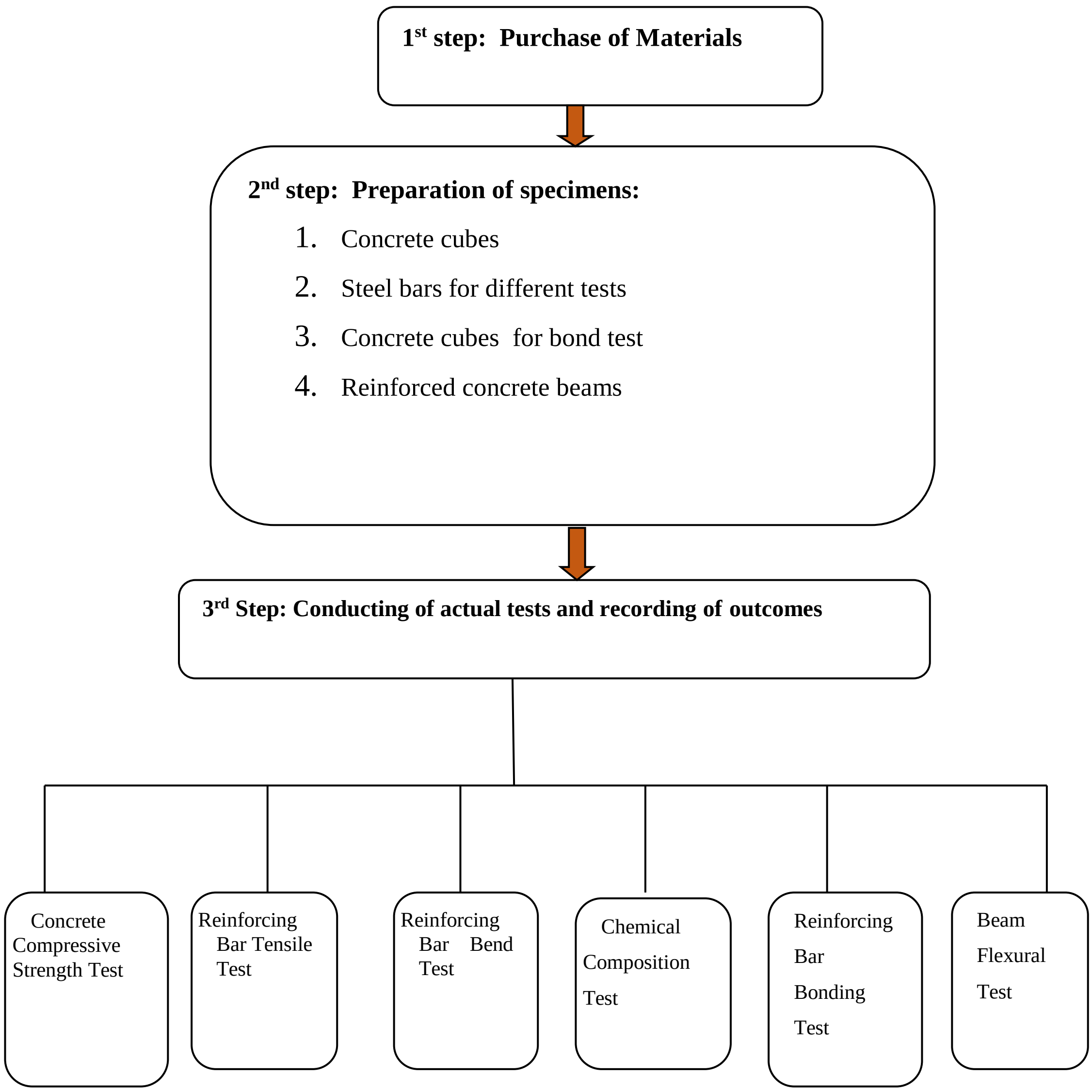


Figure 3.1: Research sequence

3.2 Materials

There are mainly three component materials that were tested in this research, these are concrete, steel reinforcing bars and reinforced concrete beam.

3.2.1 Plain Concrete

Plain concrete is concrete that is not reinforced at all by any reinforcing material, it is used for different engineering works where strength and durability are of prime importance, it is composed mainly of aggregates, cement and water in different designed ratios.

(a) Aggregates:

Aggregates used were of two type sizes, the fine aggregate which is sand and coarse aggregates which were crushed stones: Fine aggregate consisted of small angular and rounded grains which served the purpose of filling the voids existing in the coarse aggregate, to reduce shrinkage and cracking of concrete. Coarse aggregate on other hand that forms a solid and hard mass of concrete with cement and sand, serves to increase the crushing strength of concrete, reduces the cost of concrete since it occupies major volume, it is of crushed stone commonly known as ballast in mixed sizes of a half (1/2) and three quarter (3/4) inches. Both aggregates used were carefully selected to meet requirements of clean, hard, strong, and free of organic impurities and deleterious substances and relatively free of silt and clay. It was also inert with respect to other materials used and of suitable type with respect to strength, density, shrinkage and durability of the mortar made from it.

(b) Cement

The cement used was of ordinary portland cement (OPC) of 42.5 grade

Plate 3.1: Primary materials used in the research (aggregates and Cement)

(c) Water

Water used was tap water which is clean and drinkable.

3.2.2 Steel Reinforcing Bars

The Steel reinforcing bars used in this research were deformed type 2, high yield of grade 460 N/mm^2 originating from different countries namely Kenya, Rwanda, Tanzania and Turkey which are the ones predominantly used in Rwanda. Two diameter bars of 12 mm and 10 mm were collected from different warehouses each from different sources as shown in Figure 3.2:

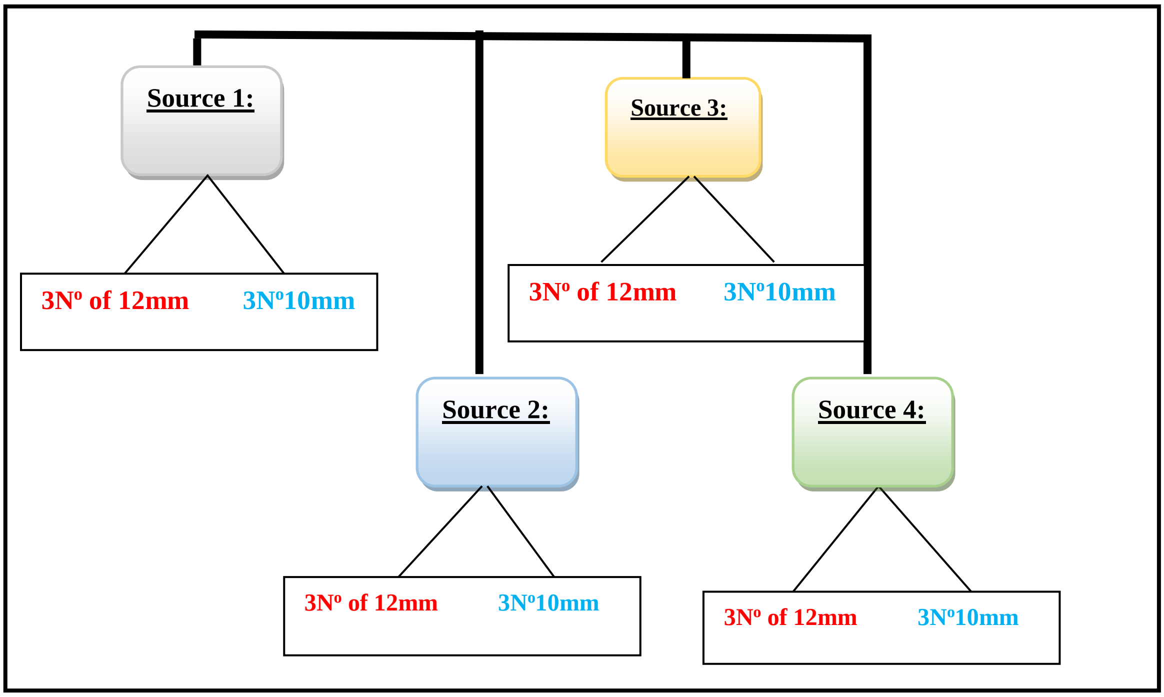


Figure 3.2: Source, size and number of the tested steel bar samples

3.2.3 Reinforced Concrete

This is a composite material composed of steel reinforcing bars and concrete which were prepared for RC beam and tested for flexural performance at 28 days of complete curing.

3.3 Preparation of Samples

3.3.1 Introduction

Samples under consideration in this research include concrete which were used in preparation of concrete cubes for compressive test; concrete cubes for bonding test, concrete for reinforced concrete beam and finally steel reinforcing bars. Concrete used in all those samples were first designed to get desired ratios for appropriate properties.

3.3.2 Concrete Mix Design

In endeavor to select suitable ingredients and determine their relative proportions that would produce concrete with minimum specified properties in both plastic and hardened states, concrete mix design was performed which started with selection of ingredients. It involves using both standard tables and graphs specifically when using DOE (British) Mix Design method, that is commonly used in Rwanda.

Table 3.1: Generated concrete mix ratios

Quantities Kg/m3	**Water**	**Cement**	**Fine aggt**	**Coarse aggt**
	210	420	531	1,239
		C	F	C
Ratios: divide all by 420 (cement content)		1	1.26	2.95
	approx	1	1.5	3

However, for trial mix 1m^3 would be big, so we used a smaller content of 0.05m3. To appropriate content we multiplied by 0.05 with all contents.

Quantities 0.05	Water	Cement	Fine aggt	Coarse aggt
	210	420=1	531 = 1.26 =1.5	1,239= 2.95 = 3
	210x0.05	420 x 0.05	531 x 0.05	1,239 x 0.05
Ratios: divide by 420 all through	10.5 kg	21 kg	26.6 kg	61.9kg
	approx	21	26	62
		21/21 =**1**	25/21 = 1.24= **1.5**	62/21 = 2.95= **3**

Giving ratio of: **1: 1.5: 3** which was adopted as the mix ratio

Figure 3.3: Concrete mix trials and measure of plastic concrete slump.

20 mm slump (1st trial) 50 mm slump which was opted for

Plate 3.2: Concrete mix trials and measure of plastic concrete slump.

3.3.3 Preparation of Concrete Cubes for Compressive Strength Test

Concrete cubes of 150mm x 150mm were prepared and tested for compressive strength with target of at least 30 MPa at 28 days of complete curing. The concrete used in this research work was made of ordinary Portland cement of 42.5 grade, crushed stone, fine and coarse aggregates plus water. The concrete mix proportion were 1:1.5:3 by weight as obtained from concrete mix design, water cement ratio was kept at 0.50 as per design results. Concrete for cubes tested were obtained from different mixed batches meant for flexural beam specimens and bonding tests. Two mix batches were prepared out of which four concrete cubes were formed from each batch making a total of eight concrete cubes were prepared and tested. First form work was fabricated and then concrete from different mix batches poured in, compacted with vibrator, on second day removed from formwork, immersed in water for 28 days before testing.

(a)Fabricated molds (b) Plastic concrete filled in molds

Plate 3.3: Preparation of concrete cube for compressive test

3.3.4 Preparation of Steel Reinforcing Bars for Different Tests

Different reinforcing steel bar samples of deformed type 2 from different established sources namely: Kenya, Rwanda, Tanzania and Turkey were collected from different stores and tested. The fact that these forms main target of this study, much emphasis was vested in them and all possible properties that may influence the flexural performance behavior was investigated. The investigated properties include tensile strength, bending, chemical composition and bonding characteristics. Twenty four (24) steel samples each of 500 mm from the four (4) sources where be prepared for the test of tensile strength, bending and chemical composition analysis where each source were represented by six (6) samples, three (3) of which were 12mm diameter and other three (3) are of 10mm diameter.

Source 1 (b) Source 2 (c) Source 3 (d) Source 4

Plate 3.4: Labelled steel bar deformed type 2 samples for different specified tests

For bonding Test, in addition to preparation of twenty four (24) steel samples steel, twenty four (24) concrete cubes of 150 mm x 150 mm x 150 mm were casted with steel bars of 12 mm diameter and 10mm diameter separately positioned vertically at the center in different cubes, on second day formwork was removed. The cubes were then completely immersed in water for 28 days before testing.

Plate 3.5: Prepared concrete cubes samples with inserted rebar for bond test

3.3.5 Preparation of Reinforced Concrete Beam Specimens

Before preparation of the beam, it was first designed based on BS 8110 to suit certain structural requirements for which reinforced concrete beams should be examined for and satisfy. Both flexural load and flexural strength were designed and compared with experimental results based on pre determined beam size, shape, rebars size and number hence the area. Beams were designed for ultimate limit state (ULS) and checked for serviceability limit state (SLS). Bending for ULS while cracking, deflection and shear for ULS.

Since our research focuses mainly on flexural performance behavior, the beam was designed and tested specifically for it. The general theory for ultimate flexural strength design took assumptions as stipulated in section 3.44 of BS 8110: 1997. Beams ware fabricated with pre determined dimensions, number of bars and size hence some parameter for beam design are already available and this eases the design.

Table 3.2: Primary information available for the RC beam design

	Design data	value
1	F_y	460 N/mm2
2	F_{cu}	30 N/mm2
3	L= over length (1800mm) – over hangs (150mm x 2)	1500 mm
4	W	150 mm
5	h	250 mm
6	d = h- conc cover- ½ bar =250-25-6= 219	219 mm
7	As (12 mm diameter) = (3.14 x 6^2) 2 =	226 m^2
8	A`s (12 mm diameter) = (3.14 x 6^2) 2 =	226 m^2
9	As (10 mm diameter) = (3.14 x 5^2) 2 =	157 m^2
10	A`s (10 mm diameter) = (3.14 x 5^2) 2 =	157 m^2
11	Steel rebars design strength = F_y / Υ_m = 460/1.15	400 N/mm2
12	Concrete design strength= $F_{cu/}$ Υ_{mc} = 30/1.5	20 N/mm2

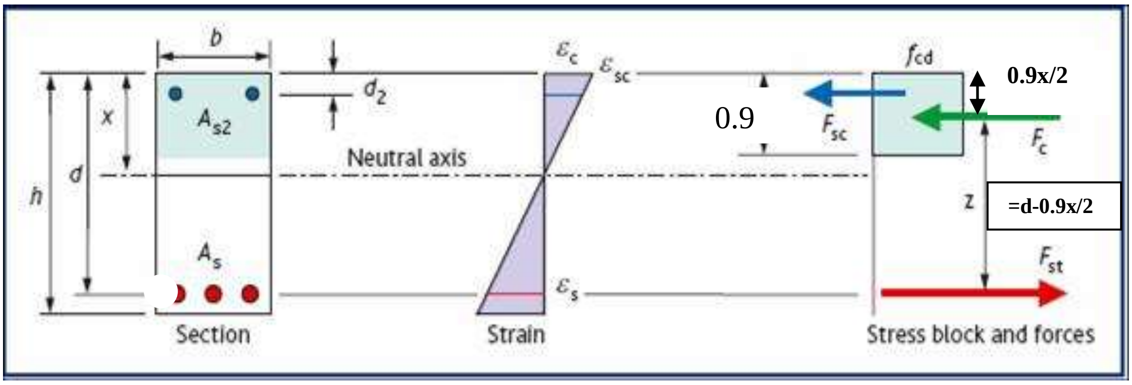


Figure 3.4: Design stress- strain block

Beam with 12mm diameter bar)……….i

1. Force carried by compression steel (F_c)=RS x As'=400x226=90,400N=90.4KN
2. Force carried by tensile steel (F_{st}) = RSxAs= 400x226= 90,400 N = 90.4 KN
3. Ratio = y_R = X_{max}/d = 0.516

X_{max} = d x 0.516 = 219 x .516= **113mm**

4. Force carried by concrete in compression area

(Nb) = b x X_{max} x compression design strength (Rb)

= 0.15 x 113 x 2 = 3.4 KN

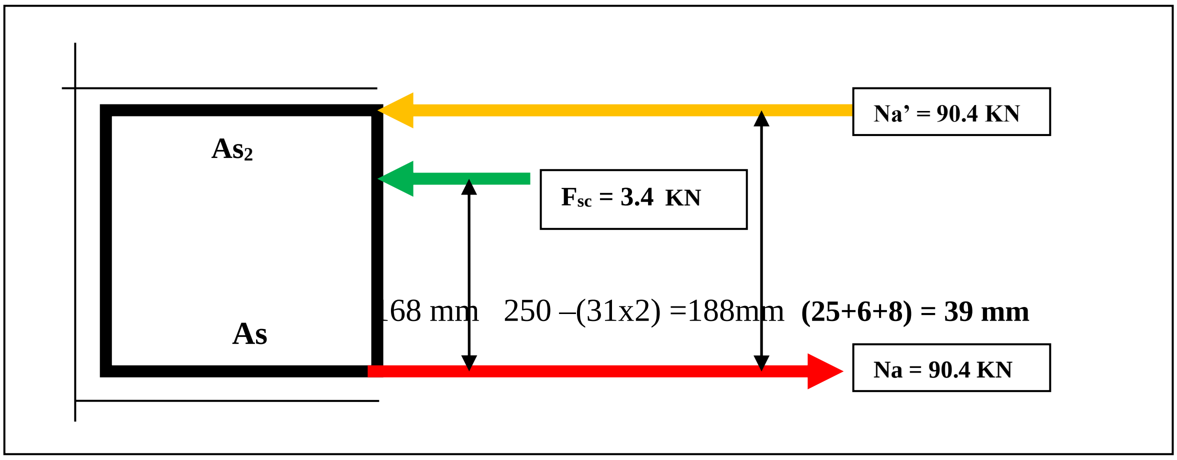


Figure 3.5: Forces acting on the Beam of 12 mm diameter bars

Taking Moments about the center of A_s

1. M= **90.4 x 0.188 + 3.4 x 0.168 = 17+ 0.57 =** **<u>17.6 KN/m</u>**

   For simple beam

   Maximum design moment (**M)= WL^2/8**

2. W = 8M/L^2 = (8 x 17.6)/ 1.5^2 = **<u>62.6 KN/m</u>**

3. Beam self-load = 0.15x 0.25 x1 x 24 = **0.9** KN/m

   Maximum live load which can be applied to the beam

   = (62.6 **-** 0.9**)** / 1.6 = 38.5 KN/m

   Maximum permanent load which can be applied to the beam

   = (62.6 **-** 0.9)/ 1.4 = 44 KN/m

   Total ultimate load (*W*) = 38.5 + 44 = 82.5 KN

   <u>Design load</u>

   F = ω × span = 82.5 x 1.5 = **<u>123.7KN</u>**

   Flexural strength = Fl/bd^2

   $$= (123.7 \text{ x } 1.5)/ 0.15 \text{ x } 0.219^2 = \frac{111{,}800 \text{ x } 1500}{150 \text{ x } 211^2}$$

   = **<u>25.8 N/mm^2</u>**

Beam with 10mm diameter bars)………………………………………ii

Force carried by compression steel (NS') = RSxAs'= 400x157= 62,800 N = 62.8 KN

Force(Load) carried by tensile steel (NS) = RSxAs= 400x157= 62,800 N = 62.8 KN

Ratio = $y_R = X_{max}/d = 0.516$

<u>X_{max} = d x 0.516 = 219 x .516= **113 mm**</u>

Force(Load) carried by concrete in compression area (Nb) =

b x $\underline{X_{max}}$ x compression design strength (Rb)

= 0.15 x 113 x 2 = 3.4 KN

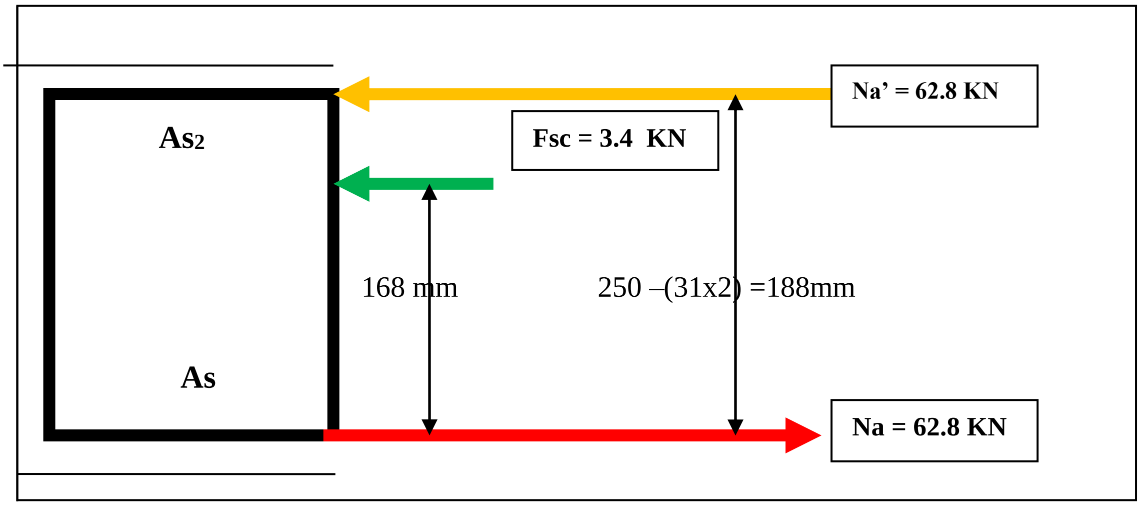


Figure 3.6: Forces acting on the Beam of 10 mm diameter bars

Taking Moments about the center of As

M= 62.8 x 0.188 + 3.4 x 0.168 = 11.8 + 0.57 = 12.3 KNm

For simple beam

M= $WL^2/8$

W = $8M/L^2$ = $(8 \times 12.3)/ 1.5^2$ = 43.7 KN/m

Beam self load = (0.15x 0.25 x1 x 24 = 0.9 KN/m

Maximum live load which can be applied to the beam =

(43.7 - 0.9)/ 1.6 = 26.7 KN/m

Maximum permanent load which can be applied to the beam = (43.7 - 0.9)/ 1.4 = 30.5 KN/m

Design load (ω) = 26.7 + 30.5 = 57.2 KNm

Design load

F = ω × span = 57.2 x 1.5 = **85.8 KN**

Flexural strength = Fl/bd^2

$$= (85.8 \times 1.5)/ 0.15 \times 0.219^2 = \frac{78200 \times 1500}{150 \times 211^2}$$

$$= \mathbf{17.9\ N/\ mm^2}$$

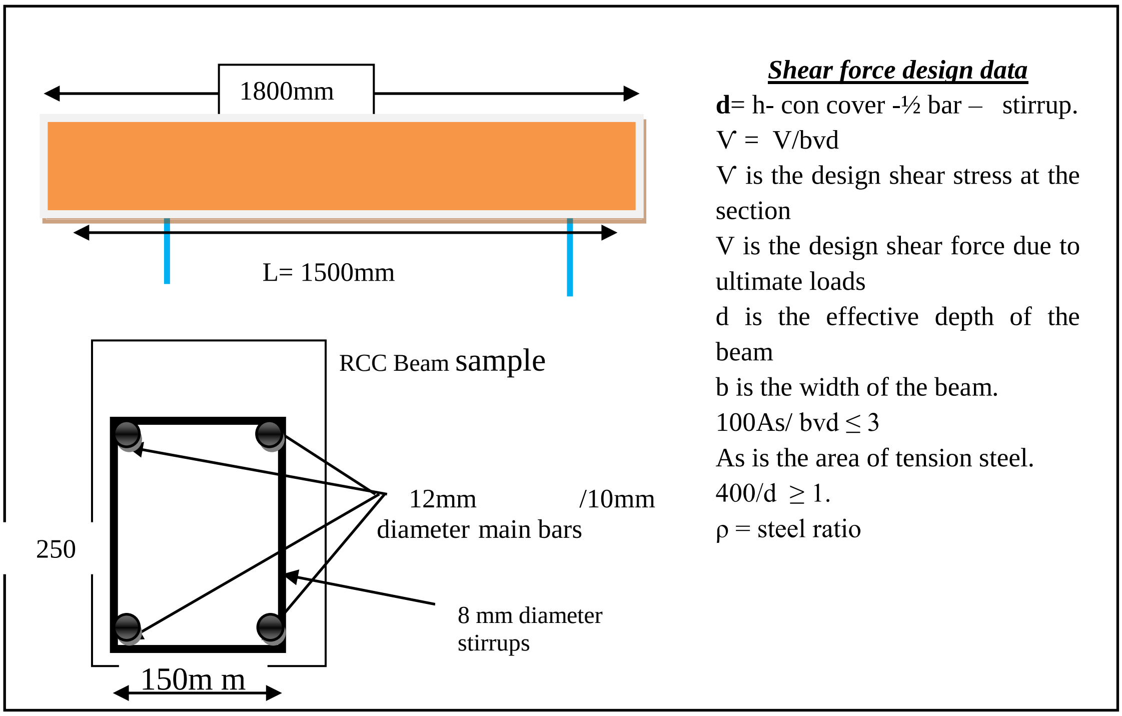


Figure 3.7: Designed RC beam sample

Steel ratio $$\rho = \frac{A}{b_w d}$$ ……………………………………….(3.4)

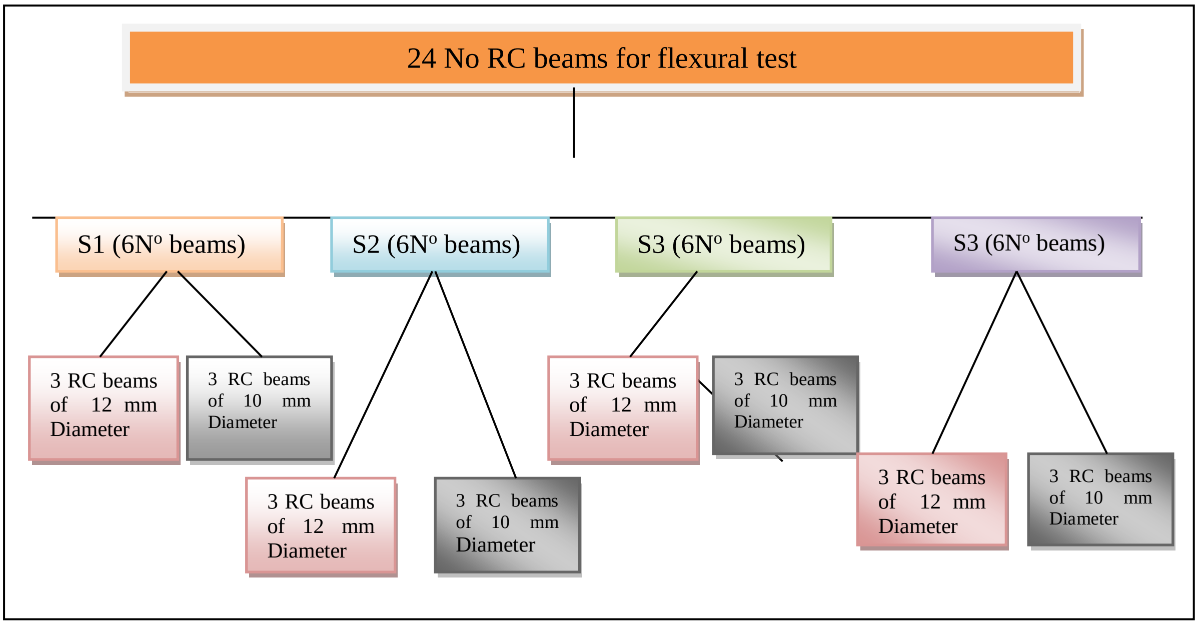


Figure 3.7: Total Number of RC beam samples tested

Twenty four (24) concrete beams of 150 mm x 250 mm x 1800 mm were prepared each with four (4) steel bars of 12 mm diameter and 10 mm diameter separately positioned at the corners held together by 8 mm ø shear bar (stirrups). Each source was represented by six (6) samples, three (3) of which were made of 12 mm diameter and three (3) of 10mm diameter.

Timber formworks were fabricated to appropriate pre- determined sizes, labeled and linseed with oil internally to ensure that concrete does not stick on formwork sides. Steel cage beams were equally prepared and arranged in four sets based on four sources. After which steel cages were put into formworks in the order of their labels and source of steel reinforcing bars. This was followed by casting of concrete in predetermined mix ratios and consistancy.

Beam formworks were rebelled for easy identification and casted for 2 days in a such way that at least each source had 3 beams of different bar sizes casted on the same day as shown in Table 3.5.

Table 3.3: RC beams labeling and casting schedule

Casted on 1st day			Casted on 2nd day		
No	**Specimens**	**Bar diameter size**	**No**	**specimens**	**Bar diameter size**
1	S_1B_1	12mm	1	S_1B_4	10mm
2	S_1B_2	10mm	2	S_1B_5	12mm
3	S_1B_3	12mm	3	S_1B_6	10mm
4	S_2B_1	12mm	4	S_2B_4	10mm
5	S_2B_2	10mm	5	S_2B_5	12mm
6	S_2B_3	12mm	6	S_2B_6	10mm
7	S_3B_1	12mmϴ	7	S_3B_4	10mm
8	S_3B_2	10mm	8	S_3B_5	12mm
9	S_3B_3	12mm	9	S_3B_6	10mm
10	S_4B_1	12mm	10	S_4B_4	10mm
11	S_4B_2	10mm	11	S_4B_5	12mm
12	S_4B_3	12mm	12	S_4B_6	10mm

Figure 3.6. Key: sample identification vs diameter bar size

Beams with bars 12 mm diameter	Beams with bars 10 mm diameter
B1	B2
B3	B4
B5	B6

(a) Beam molds (b) Beam steel cages (c) Casting of concrete in beam molds

Plate 3.6: Preparation of RC beam specimens for flexural test

Plate 3.7: RC beam, concrete cubes and bonding cubes specimens after casting

After fixing steel cages in molds, concrete was placed and then compacted using vibrator as shown above in Plate 3.6, after which they were cured for 28 days using water soaked sisal sacs as shown in Plate 3.8.

Plate 3.8: Mode of curing for RC beam, concrete cubes and bonding cubes specimens

3.4 Samples Testing

3.4.1 Introduction

Having prepared, casted and labeled RC beams and cube specimens, curing followed for 28 days. In the meantime, other tests of tensile strength, bending and chemical composition were conducted within period of curing. After 28 days of curing other tests were done concurrently where concrete cube compressive test came first followed by flexural beam test and then bonding test on the 1st day and the same procedure were followed on 2nd day.

3.4.2 Steel Reinforcing Bars Tensile Strength Test

The test specimens were marked with gauge length of 60 mm for the whole length as shown on the Figure 3.13 below:

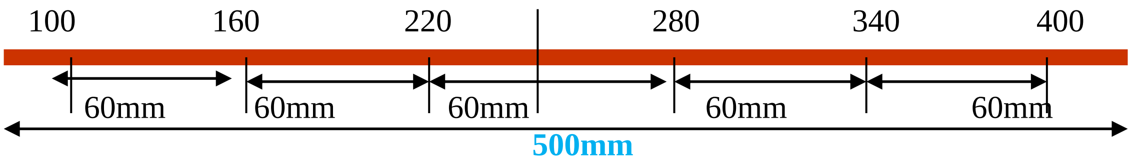
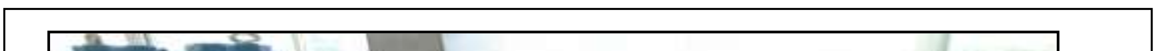


Figure 3.8: Calibrating of the steel bar for tensile strengths testing

After marking and determining the gauge length, the specimen was then loaded into the testing machine ensuring that they are equally placed between the two clamps that grips the specimen centrally to maintain axial alignment. The machine jaws were raised until they held the specimen firmly. Then extensometer was attached on to the specimen to record the



strain that is developed as the force was applied at uniform rate until the specimen raptured after which machine stopped automatically, and then the reading recorded.

Plate 3.9: Rebars tensile stress testing at different stages

3.4.3 Steel Reinforcing Bars Bending Test

The bending test was carried out in one of the steel rolling mills in Rwanda called SteelRWA, the rebar specimens were cut at sufficient length and placed horizontally between two supports on a flat plate of a bending machine just behind the mandrel of specified diameter according to RS EAS 412-2: 2014. The machine was started which applied the load continuously and uniformly through side supports for the whole bending process. The mandrel of varying diameters were interchanged to meet the requirements of specimen diameter. The machine was stopped when angles of 160^{o} and 180^{o} were reached and then specimen taken out and examined on the tension surface for fracture or cracks. Procedure was repeated for all 24 samples.

(a) Reverse bending machine (b) specimen bent at different angles (c) external inspection for any crack

Plate 3.10: Rebars bending characteristics test at different stages

3.4.4 Chemical Composition Test

The chemical analysis of the samples was carried out using spectromax equipment, specimen were grounded and put under the spark stand after which the spark was ignited on to the specimen which determines the element concentration via a quantitative measurement of the optical emission from excited atoms. The fundamental characteristic of this process is that each element emits energy at specific wavelengths peculiar to its atomic character. The intensity of the energy emitted at the chosen wavelength is proportional to the amount (concentration) of that element in the sample being analyzed.

(a) Specromax machine (b) spark stand with specimen (c) ignited spark with specimen

Plate 3.11: Rebars chemical composition test

3.4.5 Concrete Cube Compressive Strength Test: – What is the Theory?

After 28 days of complete curing, eight concrete cube specimens were taken out of the water tank on the 1st day and other four specimens on 2nd day, wiped clean and dry to remove both loose materials and water. They were then measured using a weighing scale, one by one and recorded.

The concrete cube specimens were put in the testing machine, ensuring that they are in center of both upper and lower bearing plates and ensuring that contact ends are flat and are in direct contact with both plates.

Concrete cubes under compressive strengths test at different stages and the readings

Plate 3.12: Concrete cubes before and during compressive strengths test

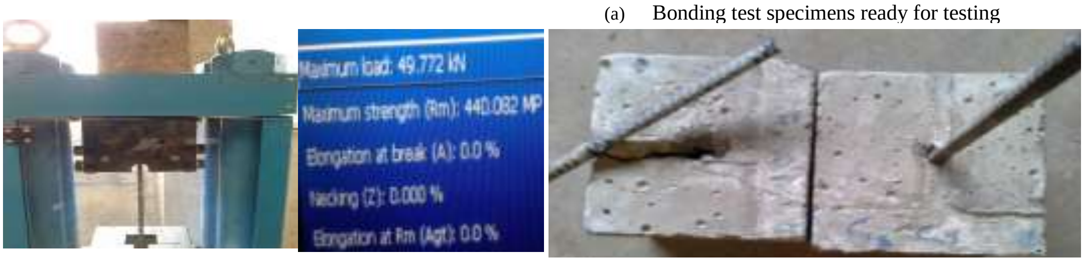
The machine was started to apply the compressive force which was exerted until specimen failed. The maximum force that crushed the specimen was read from the testing machine and recorded. This was done for all eight specimens.

3.4.6 Bonding Test (commonly known as pullout test)

The specimen which was basically a concrete cube of 150 mm x 150 mm x 150 mm with steel reinforcing bars of different sizes and from different sources, one per each cube, embedded in concrete cube vertically protruding by 760 mm to enable grip well in machine clamps.

After 28 days of complete curing, cubes were placed upside down in a UTM machine and then started which moves lower plate up to clamp and hold well the rebar. After which the tensile force was applied pulling down the rebar until the specimen failed by either rebar moving out of the cube or the bar itself breaking before coming out of the cube. The maximum force that pulled out or broke the rebar was recorded as the bond strength. At this point the machine automatically stopped when no resistance is offered by specimen to tensile force being applied.

(a) Bonding test specimens ready for testing



(b) Specimen in UTM (c) readings at breaking (d) rebar pulled out (e) re-bar breaks before pulling out

Plate 3.13: Rebars bonding properties test at different stages

3.4.7 Flexural Performance Behavior Test of the RC Beam

After 28 days of complete curing, reinforced concrete beam specimens were demolded and wiped off water and any loose substances on surface, then calibrated for the whole length of the beam. It was then placed in the UTM and subjected to flexural load until complete failure.

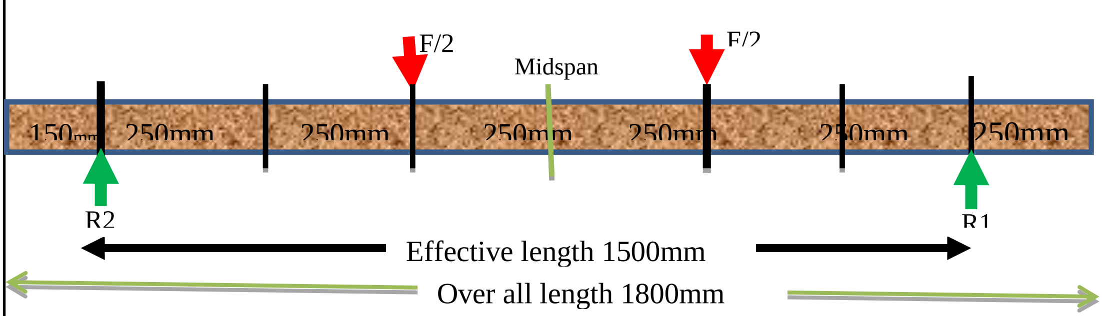


Figure 3.9: RC Beam specimen calibrating for testing

The scope of investigation of reinforced concrete beams were restricted to few areas in order reduce number of variables low enough so as to achieve detailed and definitive conclusions. Simple rectangular beams with one method of loading which is four point loading, concrete of same mix ratio and same slump were used, beams of the same size of 150 mm by 250 mm by 1800 mm length were used and tested at the same age after 28 days.

(a) Specimens ready for testing

(b) specimen under testing machine

Plate 3.14: RC Beams after 28 days of complete curing

The flexural test on the concrete beams was carried out on Universal Testing Machine (UTM); all specimens were simply supported and subjected to four-point loading. Each of the specimens had a clear span of 1500 mm and over hangs of 150 mm. The load was applied vertically at the center of RC beam by a hydraulic jack which transmitted the load on to specimens through a steel spreader laid two bearings on top of the beam spaced at 500 mm. A loadcell was connected to specimen to measure applied loads, strain gauge attached on the surface of the RC beam to measure surface strains at three specific points of midspan and shear ends, displacement transducer (LVDT) placed at beam midspan to monitor deflection of beams at different incremental loadings, all of which were then connected to a data logger which registers the measured data.

The load was applied to the beam until the first crack was noticed and corresponding load and deflections were recorded, and then at regular intervals until the final collapse of the beam was reached. At the end of each load increment, the load was held constant, and crack patterns were marked.

The four-point bending arrangement was considered to be more effective than the alternative three-point bending arrangement in this case as the spacing between applied loads. The major difference being that the addition of a fourth bearing brings a much larger portion of the beam to the maximum stress, as opposed to only the material right under the central bearing. This difference is of prime importance when studying brittle materials, where the number and severity of flaws exposed to the maximum stress is directly related to the flexural strength and crack initiation.

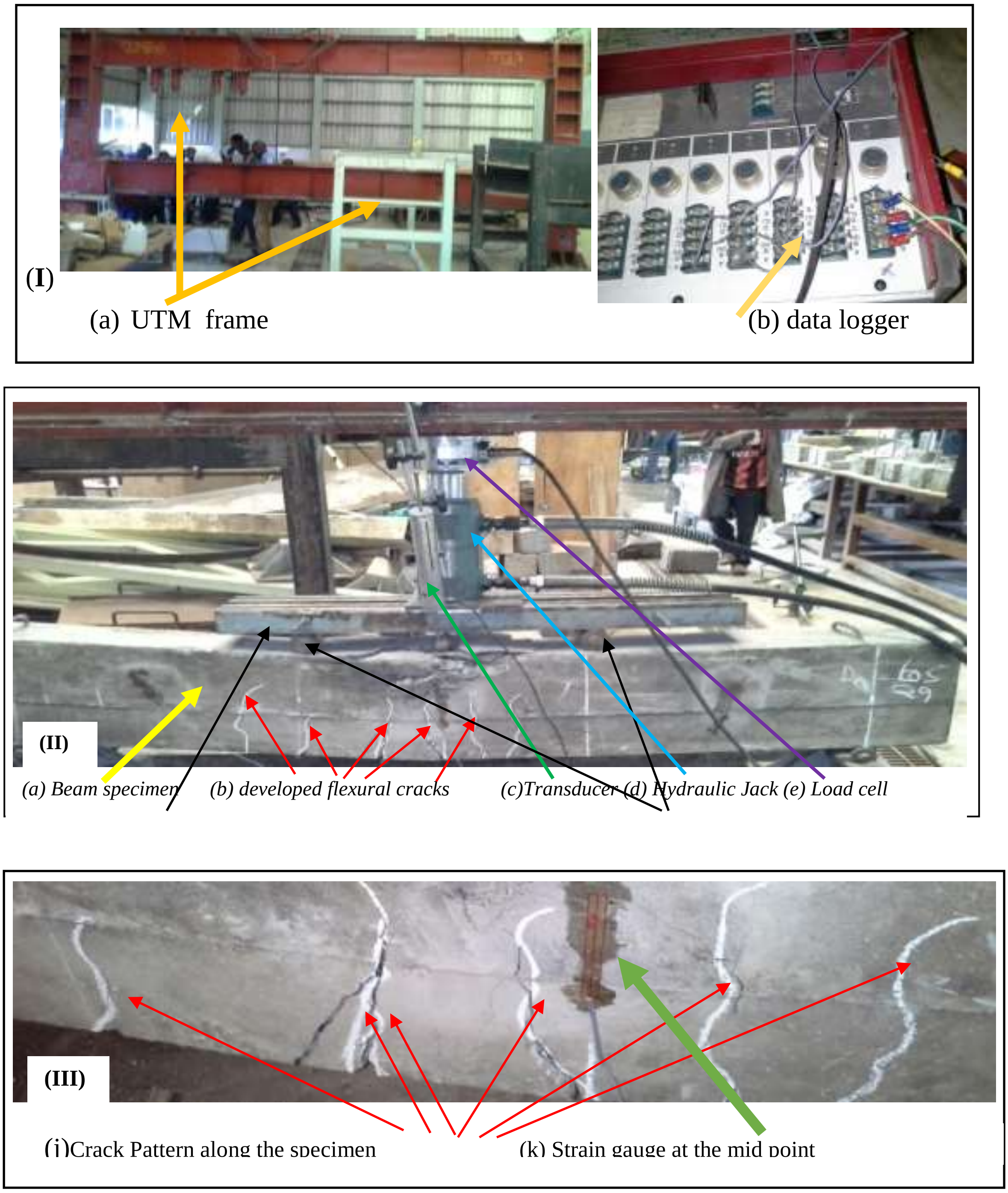


Plate 3.15: (I-III) RC beam flexural test

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the analysis and detailed discussion on the findings from the materials' physical properties investigations, mechanical properties experimental results, chemical composition analysis and finally RC beam flexural performance behavior.

The investigation started with visual verification of the physical features on steel reinforcing bars of high yield deformed type 2, this involved taking measurements for the length and nominal diameters, and then assessed rib pattern and markings on the rebars.

It was found out that no single brand or source from all four sources met all combined physical standard code requirements as shown on plate 4.1, while mechanical and chemical analysis, confirmed legibility parameters falling within standard limits apart from only one brand. The other experimental results such as reinforced concrete beams flexural performance behavior results were compared with design results and previous tests encountered in literature review to assess whether they were within the range limits.

4.2. Steel reinforcing Bars' Physical Features Verification.

Physical features assessment were referenced to BS 4449: 1997 and RS EAS 412-2: 2014 standard codes. The assessment found out that all bars from all four sources had different markings that were not harmonized at all, while some bars indicated only country of origin such as Kenya, Turkey and did not indicate the rolling mill while others indicated only rolling mill with no country of origin, with no bar type, size nor grade. Some marks found on rebars were not recognizable at all neither by sellers nor regulatory organs such as RSB. To make it worse some were not labeled at all, a situation that rises a lot of concern whether regulators are in control.

Table 4.1: Findings on physical features verification

No	Source	Item inspected	Observation	BS 4449: 1997 requirements
1	S_1	Bar length Vs 12m	Length were in normal range of 11.94m	Diameter deviation
		Bar diameter Vs 12 and 10 mm diameter	Diameters were in normal range of 12 and 10 mm diameter	tolerance: ≤ 8 %.
		Bar Marking	Marked country of origin and size no rolling mill, no bar types, nor grade.	*Length deviation tolerance:*
		Bar ribs	Height, spacing, inclination and firmness met requirements	≤ 100 mm.
2	S_2	Bar length 12m	Some bars had length in normal range of 11.92m, while others were abnormally short with 11.6m	Bar marking, code requires rebars to
		Bar diameter Vs 12 and 10 mm diameter	Diameters were in normal range 12 and 10mm diameter	bear: (i) Norminal size (ii) Steel grade
		Bar Marking	Marked rolling mill , bar size, bar types and bar grade but no country of origin	(iii)Bond classification
		Bar ribs	Height, spacing, inclination and firmness met requirements	EAS, 412: 2
3	S_3	Bar length 12m	Length were in normal range of 11.93m	requires all rebars to bear;
		Bar diameter Vs 12 and 10 mm diameter	Some bar diameters were abnormally smaller than their normal size 10.5 mm and 8.5 mm diameter respectively.	(i)Name of manufacturer (ii) Steel grade (iii)Norminal
		Bar Marking	No marks at all	diameter
		Bar ribs	Height, spacing, inclination met the requirements but firmness did not meet the requirements as the they appeared to be loose.	(iv) Cast number
4	S_4	Bar length 12m	Length were in normal range of 11.98m	
		Bar diameter Vs 12 and 10 mm diameter	Diameters were in normal range. 12 and 10 mm diameter	
		Bar Marking	Marked country of origin and size no rolling mill, no bar types, nor grade.	
		Bar ribs	Height and firmness did not meet requirements	

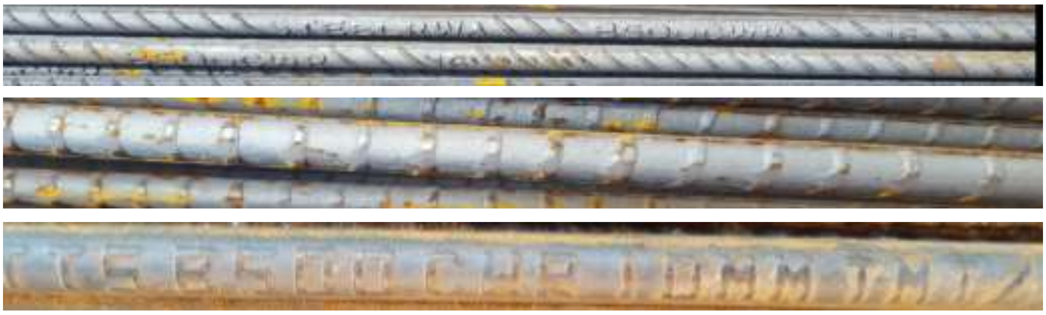


Plate 4.1: Different Types of bar labeling found on local market

As may be seen from Plate 4.1, there was a significant mismatch to standard codes with obvious quality consequences: to begin with diameters that are much lower than standard requirements have a very serious implications to design resulting from under estimation of steel area (Ast) and eventually under design. Regarding bar ribs where some are very loose while others do not meet standard height, this has a very serious impact of poor bonding with subsequent steel slip out and structure failure.

The other factor of failure to have a proper bar marking may be interpreted as disguise to traceability in case of failure and obviously with intention of production substandard products. while short of proper length is an intended act of steel producers and importers with purpose of cost saving and loss to buyers whose length in 12mm unless otherwise.

4.3 Compressive Cube Tests Results

As stated in chapter three, compressive tests were conducted on well prepared concrete cubes and monitored to ensure genuine results gauged on BS 4449: 1997 and EAS 412-2: 2014.

All concrete cube samples met the targeted minimum compressive strength of 30 N/mm^2, results were in range of 33.2 to 37.76 N/mm^2. This gives surety of strength of concrete used in the investigation of both steel reinforcing bars bond characteristics and RC beam flexural performance strengths.

Table 4.2: Compressive strength test results

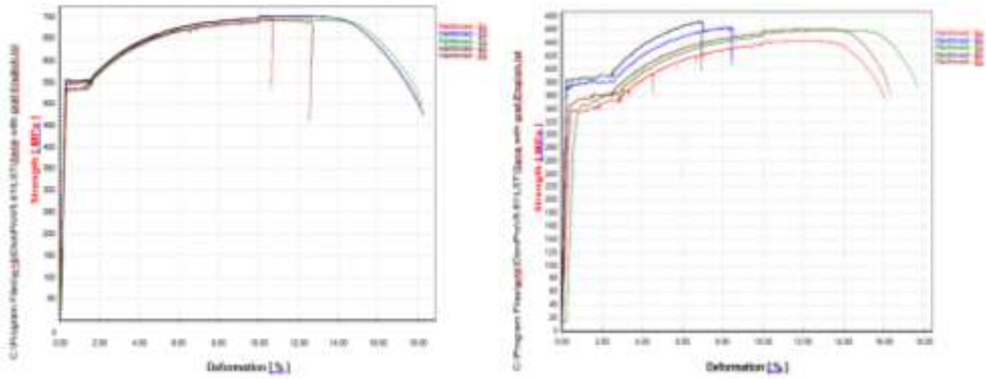
1^{st} day: A= 22,500 mm^2				2^{nd} day: A= 22,500 mm^2			
Sample	Weight as read from Scale	Maximum load as read from Machine	Maximum strength (W/A) N/mm^2	Sample	Weight as read from Weighing Scale	Maximum load as read from Machine	Maximum strength (W/A) N/mm^2
01	7920.5	862	38.3	05	8339	837	37.2
02	7995	747	33.2	06	8542	828	36.8
03	8150	754.4	33.531	07	8331	846	37.6
04	8121	826.9	36.750	08	8319	849.6	37.76

4.4 Tensile Strength Test Results and Discussion

Test results were consistent for each sample as evidenced from Figure 4.1 (a and b) where each of the five stress – strain curve were approximately overlapping. It's also important to note that two samples of Y12mm bar lost stress so suddenly, a fact that may be attributed by the lack of ductility, while on Y10mm they actually don't overlap but still some two samples dropped so suddenly, just after yield point without necking which is a sign of poor ductility.

It is apparent that yield strength of 11 samples out of 24 fell below standard code requirements which means 45.8 % of total tested samples failed to meet high yield steel requirements of 460 N/mm^2. Tested samples of size 12 mm which were 12 in total only 3 samples did not meet the standard requirements meaning only 25% bars failed. On the other hand of 10mm diameters bars 8 samples out of 12 failed which makes 67%.

This poses a very serious concern on strength and stability of 45.8% for structures and buildings used by these rebars are in question. The ultimate tensile strength results shown in Figure 4.3 indicate that in average three sources S1, S2, and S4 are in the same range while S3 still performas badly as is the case of yield strength. Ultimate tensile strength being the point beyond which the material fails completely was assessed in comparision with yield strength through analysis of ultimate tensile strength to yield strength ration (Rm/Re) the justifies ductility.



(a)Ribbed Steel bars; diameter: 12mm (b) Ribbed Steel bars; diameter: 10mm

Figure 4.1: Stress-strain curve for some tested steel bars samples

Typically, there is a significant variation in yield strength while ultimate strengths seem to be quite close. Its anticipated that observed poor yield strengths will have considerable effect flexural strength of the beam. The horizontal line on Figure 4.2 indicate cutoff point above which gives samples that met the standard code requirements and whose below shows those that failed.

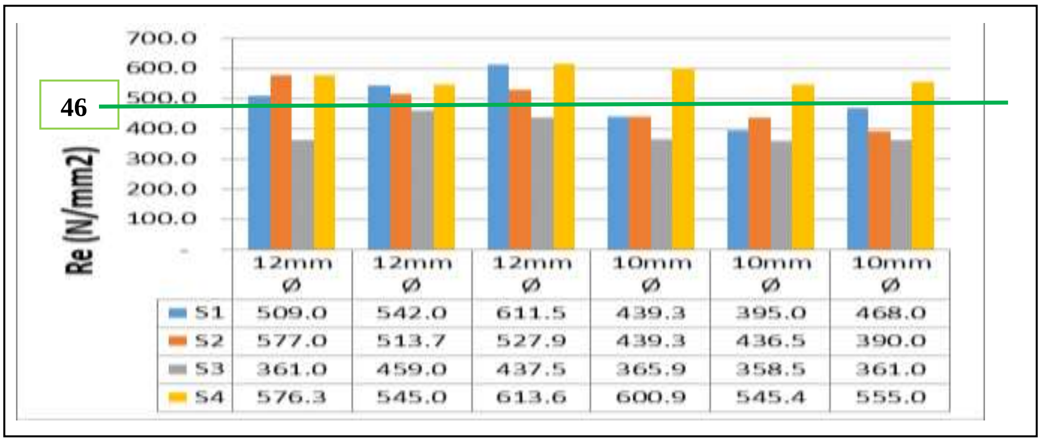


Figure 4.2: Yield strength (Re) results comparison

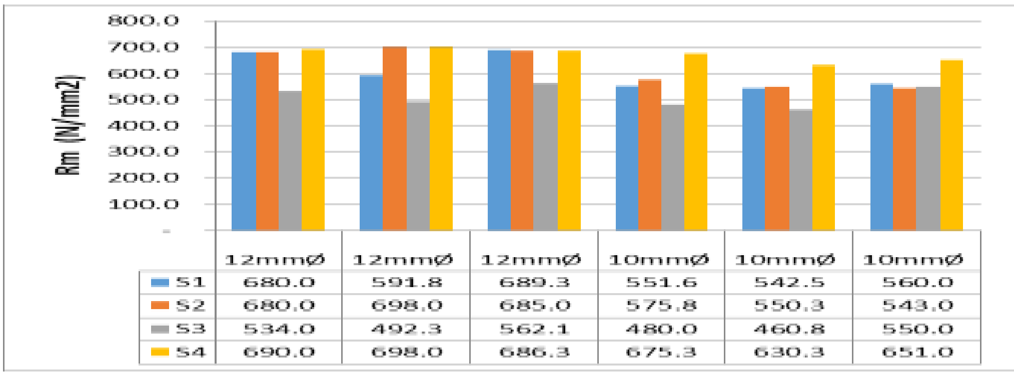


Figure 4.3. Ultimate tensile Strength (Rm) results comparison

From the Figure 4.4 of ultimate tensile stress to yield stress (Rm/Re) ratio, only 2 samples out of 24 did not meet the requirements of BS 4447: 1997 and RS EAS 412-2: 2014 which sets the minimum value at 1.08 for high yield steel bars, definitely the higher the value the better quality is the sample, they have demonstrated the ductility required by standard code requirements. However as said above this value should not be appreciated in isolation to other primary factors such yield stress. As may be seen from above Figure 4.2, sample 3 (S3) performs well but it becomes meaning less when compared to its yield stress which does not meet the requirements itself. Actually, specifically on this sample further analysis may not be required if first requirement is not met. Again, it should be noted that samples that failed to meet Rm/Re requirement are the same samples that had sudden curve drop in Figure 4.1.

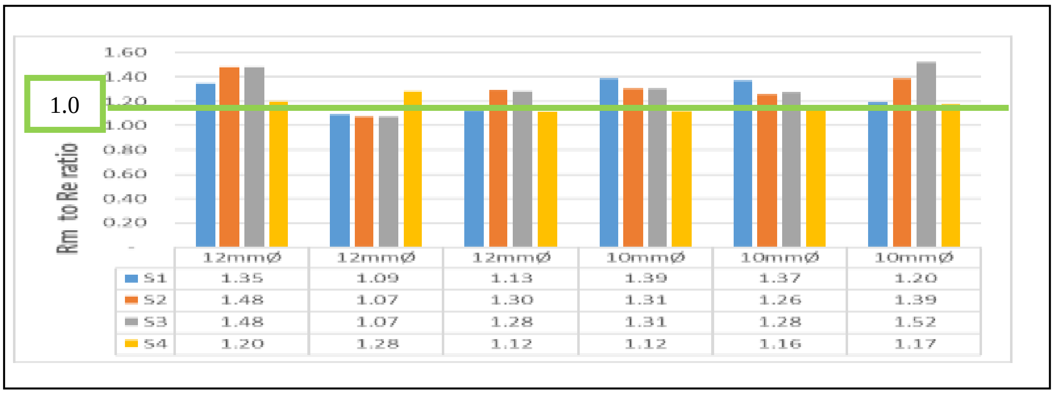


Figure 4.4: Average UTS to YS Ratio (RM/Re) results comparison

4.5 Bending Test Results with High Yield Steel Bars of Deformed Type 2.

BS 4449:1997 and RS EAS 412-2 (2014) codes stipulates that specimens must undergo bend test and shall show no sign of fracture or irregular bending deformations. All samples tested did not show any sign of fracture or irregular bending deformations as indicated in Table 4.3 and hence met the requirements of the code. That is justified by other factors such as results of elongation, the ultimate tensile stress to yield stress ratio all of which portrays clearly ductility within tested samples. This further gives confidence on stability of structures and buildings they reinforce and justifies why no rampant failures within structures despite low yield strength obtained in rebars.

Table 4.3: Average bending test results

S/No	Identification No	Bar Size Diameter	Former Diameter	Observation
1	S1	12 mm	3d	No crack observed
		10 mm	3d	No crack observed
2	S2	12 mm	3d	No crack observed
		10 mm	3d	No crack observed
3	S3	12 mm	3d	No crack observed
		10 mm	3d	No crack observed
4	S4	12 mm	3d	No crack observed
		10 mm	3d	No crack observed

4.6 Bond/ Pull Out Test Results with High Yield Steel Bars of Deformed Type 2.

Results signifies the yield strength of the tested bars, all the bars that broke actually had lowest yield strength values, far below the standard code requirements. As may be observed from Table 4.4 and Figure 4.5 that 14 out of 16 samples were pulled, the two that broke before being pulled out were from source 3(S3) size 10 mm diameter.

The only reason that surround this total bar breakage is the less yield strength envisaged in rebars compared to other bar samples. Eventually this may have a serious instability effect on structures reinforced with these rebars that failed. This may as well be traced on stress – strain curve Figure 4.1 with two samples showed sudden drops indicating being brittle in nature.

Table 4.4: Average bonding test results

SN	Specimens source & Diameter	Maximum load at failure (KN)	Mode of failure	SN	Specimens source & Diameter	Maximum load at failure (KN)	Mode of failure
1	$S_1C_{1:}12$	51.5	Pulled out	5	S_1C_2:10	50.5	Pulled out
	$S_1C_{3:}12$	51.7	Pulled out		$S_1C_{4:}$ 10	50.6	Pulled out
2	$S_2C_{1:}$ 12	50.8	Pulled out	6	$S_2C_{2:}$ 10	50.1	Pulled out
	$S_2C_{3:}$ 12	51.1	Pulled out		$S_2C_{4:}$ 10	50.4	Pulled out
3	$S_3C_{1:}$ 12	50.4	Pulled out	7	$S_3C_{2:}$ 10	49.8	Breaking
	$S_3C_{3:}$ 12	50.8	Pulled out		$S_3C_{4:}$ 10	49.7	Breaking
4	$S_4C_{1:}$ 12	51.7	Pulled out	8	S_4C_2 : 10	50.7	Pulled out
	$S_4C_{3:}$ 12	51.9	Pulled out		S_4C_4 :10	50.9	Pulled out

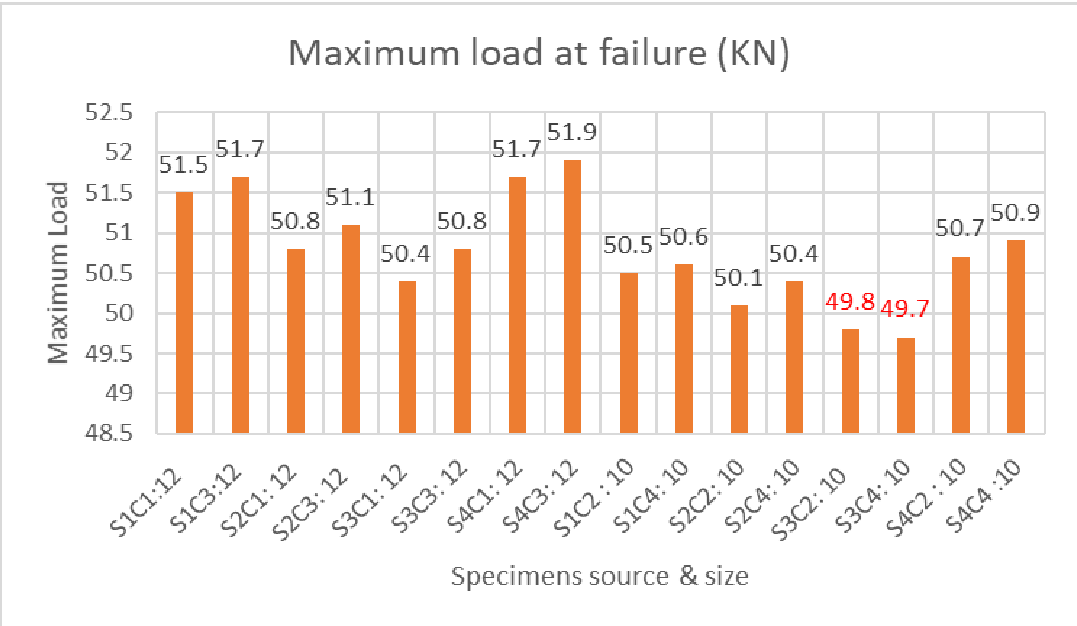


Figure 4.5: Average bonding test results

4.7 Steel Bars Chemical Composition Test Results

The chemical composition of samples were tested for: Carbon, Sulphur, Phosphorus, Nitrogen and carbon equivalent value. Results for all samples are tabulated in Table 4.5

which demonstrate presence of appropriate portions of chemical compositions in all tested samples except nitrogen. It is important to note that most notable ingredients within rebars were found in appropriate portions.

Carbon which is most important alloy of steel with properties that control hardness, strength, weldability and ductility was found to be within limits of requirements; Carbone equivalence (CEV) that influences weldability of steel were equally found within acceptable limits.

Nitrogen content values however, were found to be higher than standard values, the effect of nitrogen in steel is obviously significant. According to Kant (2016) nitrogen improves yield strength, grain size and mechnical properties provided its harmful effects are fixed by nitrogen binding elements. This is further retariated in BS 4449 : 2005 where it stipulates that higher nitrogen contents are permissible if sufficient quantities of nitrogen binding elements are present some of which include chromium and vanadium.

This may justify why Nitrogen content was put in excess perhaps to improve yield strength and grain size and yet with no effects on other properties.

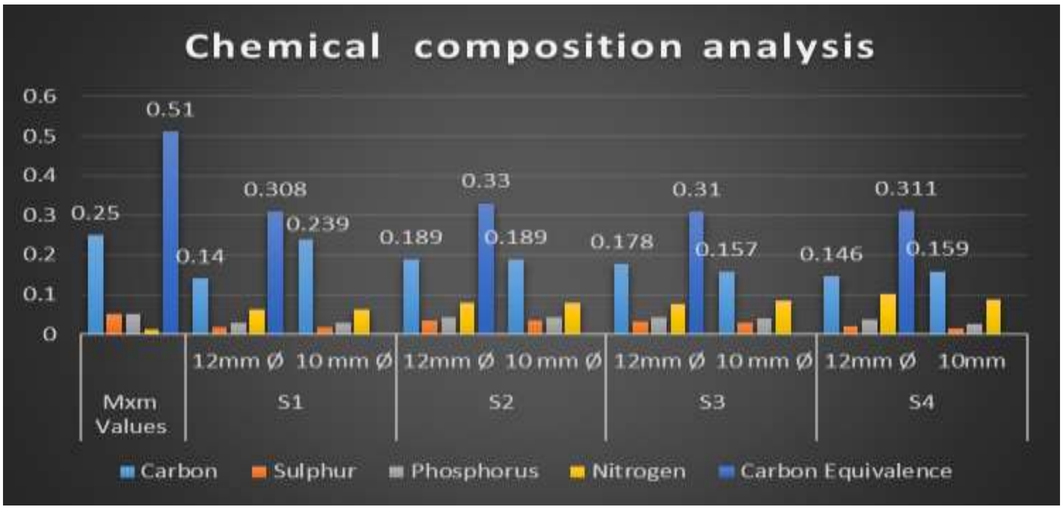


Figure 4.6: Chemical composition test results

4.8 Steel reinforcing bars cost comparison

Steel reinforcing bars cost analysis was conducted in the interest of assessing relationship between cost with their subsequent yield strengths (Re), baseline being assumption that the higher the cost the higher the tensile strength and the better quality. It was observed that for 12mm bars the assumption of "the higher the cost the higher the tensile strength" came true. Cost of rebars followed the order of: S4 > S1 > S2 > S3 and this has the same order of tensile strengths (Re): S4 > S1 > S2 > S3, and higher ultimate tensile strength (Rm) which exactly matches its higher cost. However, assessing the difference between yield strengths for different rebars with their subsequent costs difference does not make any proportionality, yield strengths seem to be very close while cost deference seem to be high. In over all assessment, higher cost does not justify the quality of the bar, however, one can easily say that the lowest cost justifies poor quality.

Figure 4.7: Rebars cost comparison: Y12 mm (frw/m)

Figure 4.8: Rebars cost comparison: Y10 mm (frw/m)

4.9 RC Beam Flexural Performance Test Results

(a) Ultimate load

When carefully analyzing the flexural performance and mode of failure for RC beams tested samples, they all passed through three substantial phases of un cracked, cracked and failure which translates into elastic, semi elastic and plastic regions respectively. In first region loads are direct proportional to deflection hence the elasticity, this region end with appearance of first crack caused by cracking load (Pcr). In the second region after appearance of the first crack, the proportionality of loads and deflection is lost, where deflection is a little bit higher at an equal loading increment as compared to pre-cracking region. At this point steel is said to have started yielding with yielding load (Py) and concrete starts loosing strength to support applied loads.

The third region indicates plasticity state, where any small increase on applied load causes abrupt increase of the deflection, fully cracking intensity becomes rampant with ultimate load (Pu) leading to total failure.

Y 12 mm beams:

It is observed that 3 beams of $S_{1,2\ \&4}$ show similar curve slope from zero (0) to 1st crack which is mainly a straight line indicating linear-elastic behavior, quite different from $S_{3.}$ This difference behavior between samples is a result of difference in steel bars' yield strength values as indicated in Figure 4.2 and this was expected since S_3 rebars had extremely lower values of yield strength which did not meet code requirements.

After occurrence of first crack, proportionality of loads and deflection got lost with drop of the curve which is still normal for load deflection curves, however the worst scenario was S3 with significant curve drop. The implication is that before 1st crack both concrete and steel bars participate in resisting the applied loads, however after that point steel bars takeover and this is confirmed by S_3 curve behavior which shows a consideration deflection which further justifies the influence steel bars.

From yield point to ultimate point the curve further dropped though at different magnitude, the deference between two values of yield load and ultimate loads for all beams are totally different, some values are closer than the others which further indicates difference in ductility of steel bars that reinforced the samples. After ultimate point all samples indicated plasticity behavior at failure, there was a gradual mode of failure which is justified by the fact that all steel reinforcing bar sample Rm/Re ratio mate standard code requirements of 1.08 for high yield deformed bars.

The behavior of S_3 beams was totally different from other beams right from starting slope, to the end at failure where the sample showed a sudden failure. It should also be observed from Figure 4.10 that it is the only sample that did not meet the design load of 123.7 KN as indicated by cutoff line hence obvious failure.

Y 10 mm beams:

For beams of Y10 mm bars, the failure mode was almost same as for Y 12mm bars the difference being at starting point to yield point where all curves had the same slope and at failure point where S3 showed some ductility. It's also important to note that all experimental loads were found exceeding the design loads of (85.8 KN) with good safety margins, as the least flexural experimental load observed was 93.0 KN. This is indicated on Figure 4.12 with horizontal cutoff line.

Table 4.5: RC Beam Y_{12mm} Average Load - Deflection Results

Average values of Load & Deflection for a RCC Beam of 12mm bars								
S1:B1,B3 & B5		S2: B1, B3 & B5		S3: B1, B3 & B5		S4: B1, B3 & B5		
Load	Dflctn (mr	Load	Deflectn	Load	Deflectn	Load	Deflectn	Failure status
0	0	0	0	0	0	0	0	
95.5	3.5	96.2	3.2	68.8	3.7	107.5	3.5	load at 1st Crack
127.3	7.4	131.5	7.5	103.7	8.8	134.9	6.6	Yield load
130.2	9.4	135.3	9.1	114.6	11.2	142.6	9.9	Ultimate load
122.0	15.0	127.0	14.7	103.1	16.6	138.0	13.5	Descending loads 1st
111.3	20.0	110.5	20.3	74.1	20.7	124.1	19.3	Descending loads 3rd

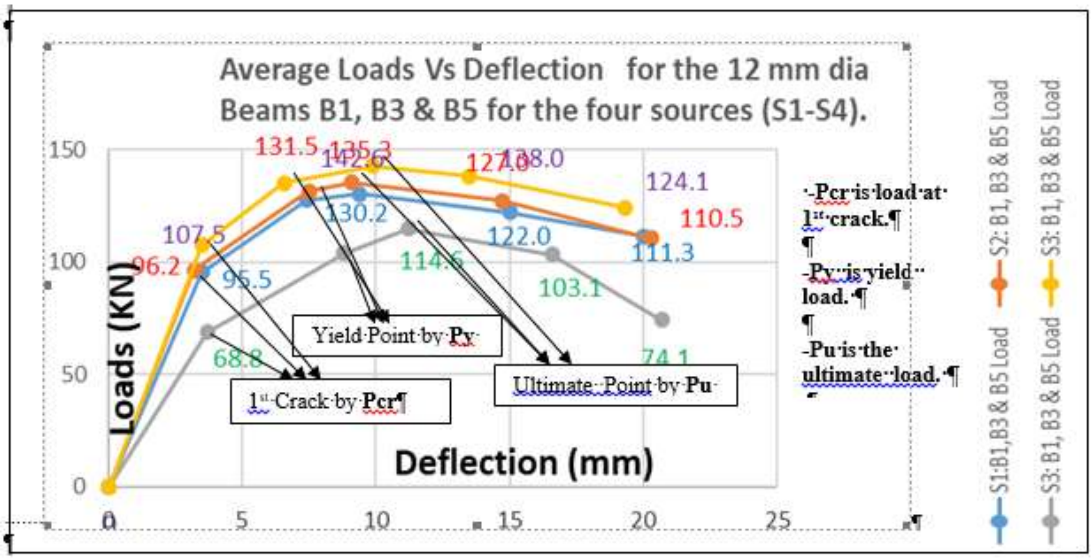


Figure 4.9: RC beam -12mm bars: load-deflection curve

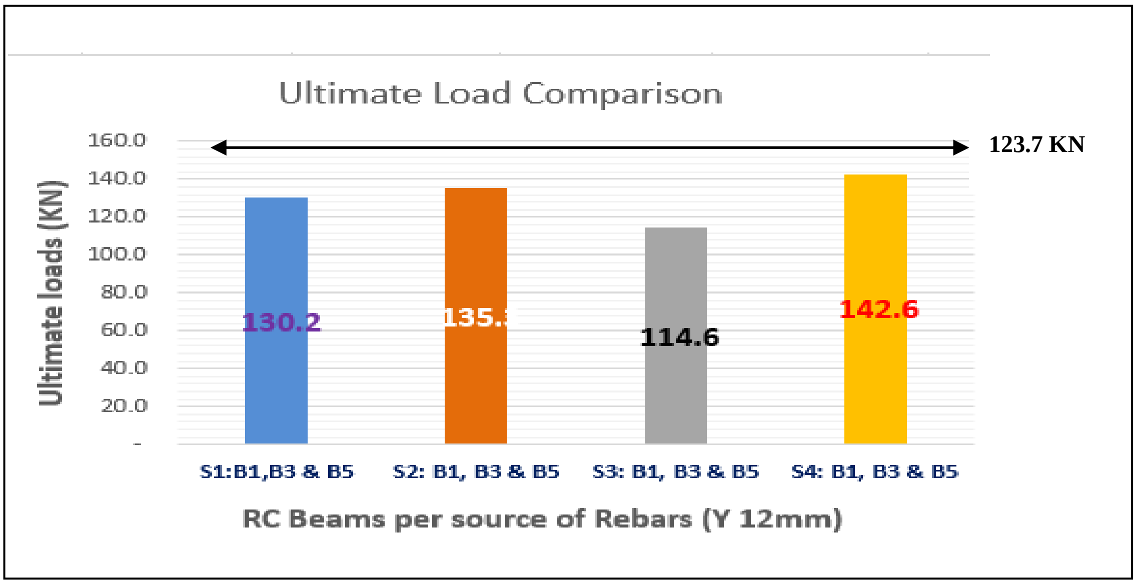


Figure 4.10: RC beam -12mm bars: Ultimate loads Comparison

Table 4.6: RC Beam Y10mm Load-Deflection Results

Average values of Load & Deflection for a RCC Beam of 10mm bars								
S1:B1,B3 & B5		S2: B1, B3 & B5		S3: B1, B3 & B5		S4: B1, B3 & B5		
Load		Load		Load		Load		Failure status
0	0	0	0	0		0		
63.8	2.6	55.8	2.7	51.5	2.4	73.2	2.5	Cracking load (Pcr)
103.3	6.8	99.0	7.1	82.5	8.0	123.9	6.9	Yield load (Py)
114.4	9.9	107.7	10.7	93.0	10.0	131.5	10.9	**Ultimate load (Pu)**
108.6	13.6	99.9	16.2	87.0	14.0	120.7	14.9	Descending loads 1st
90.0	20.5	90.0	20.1	60.3	20.0	110.7	19.5	Descending loads 3rd

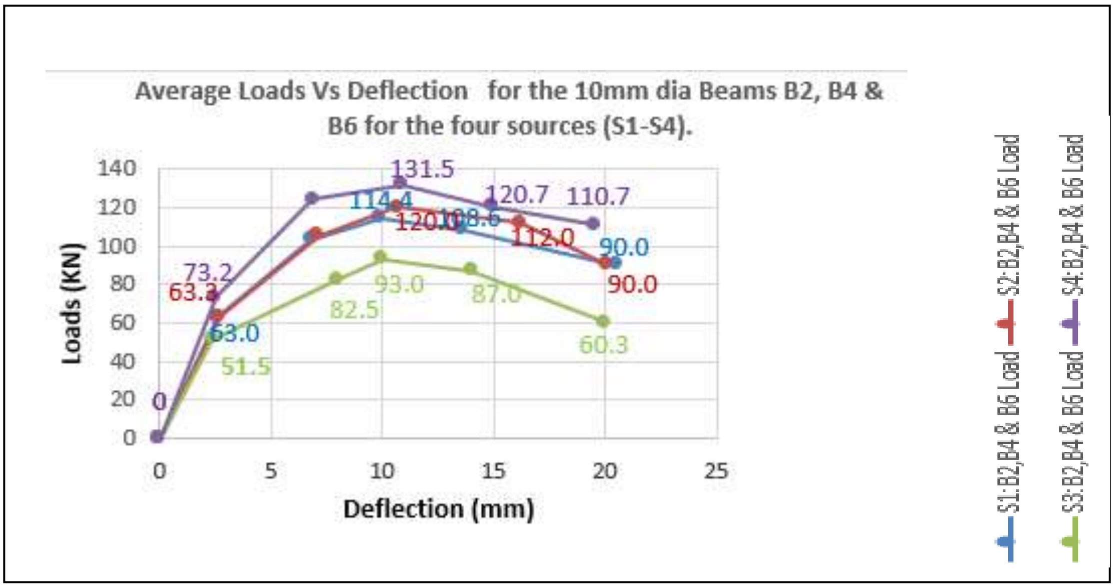


Figure 4.11: RC beam -10mm bars: load-deflection curve

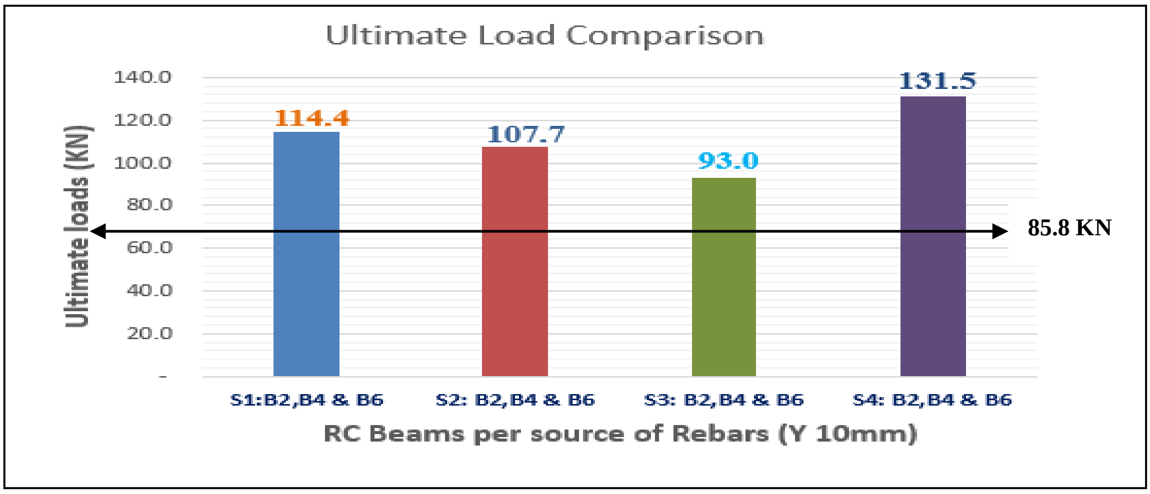


Figure 4.12: RC beam -10mm bars: Ultimate loads Comparison

In comparison of different loads at different points of failure: first crack, yield point and ultimate point for different samples. It was observed that loads that caused first crack in all beams were different in magnitude with S_4 being the highest and S_3 being the lowest which is directly related to yield strength of their respective steel bars. As may be drawn from Figure 4.13.

Pcr for: $S1_{12}$ = 95.5 KN, $S2_{12}$ = 96.2 KN, $S3_{12}$ = 68.8 KN, $S4_{12}$ = 107.5 KN

$S1_{10}$ = 63 KN, $S2_{10}$ = 63.3 KN, $S3_{10}$ = 51.5 KN, $S4_{10}$ = 73.2 KN

It can be noticed that loads caused effect of 1st crack on source 1 beam of 12 mm bars ($S1_{12}$) is slight related to source 2 beam of 12 mm bars ($S2_{12}$) but much higher than source 3 beam of 12 mm bars ($S3_{12}$), while loads that caused 1st crack source 4 beam of 12 mm bars ($S4_{12}$) are much higher than all others. It is worth noting also that loads that effected 1st crack of source 4 beam of 10 mm bars ($S4_{10}$) are much higher than loads that effected 1st crack on source 3 beam of 12 mm bars ($S3_{12}$). This means that beams of 10 mm source S4 performs structurally much better that beams of 12 mm source S3 irrespective of bar size.

Py for: $S1_{12}$ = 127.3 KN, $S2_{12}$ = 131.5 KN, $S3_{12}$ = 103.7 KN, $S4_{12}$ = 134.9 KN

$S1_{10}$ = 103.3 KN, $S2_{10}$ = 105.3 KN, $S3_{10}$ = 82.5 KN, $S4_{10}$ = 123.9 KN

Yield load effects followed the same trend 1st crack effects where **Py ($S4_{12}$) > ($S2_{12}$)> ($S1_{12}$)> ($S3_{12}$) and equally ($S4_{10}$) > ($S3_{12}$).**

These results has similarity with yield strength results Figure 4.2 where source 4 beam of 10 mm bars ($S4_{10}$) has 545.5N/mm2 while source 3 bars of 12 mm bars ($S3_{12}$) has yeld stterength of 459. N/mm2.

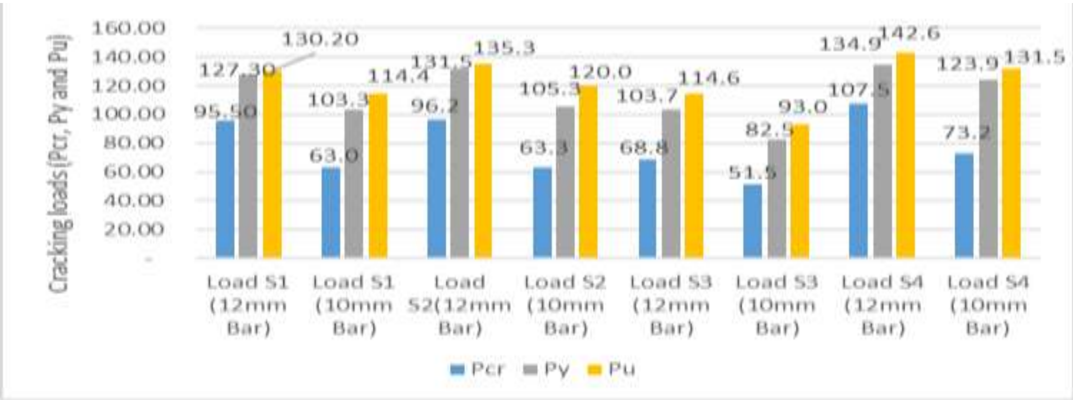


Figure 4.13: Comparison of effects for different loads on different RC beam

(b) RC beam Flexural strength results

Again, like flexural loads, experimental flexural strength of Y12 beams supersedes the design flexural strength with some good safety margin apart from S3 beams whose experimental flexural strength value is 25.7 N/mm2 which is very close design load of 25.9 N/mm2. This is different for the case of Y10 beams where experimental flexural strength superseded the design flexural strength with good safety margin, as may be seen from Figure 4.15.

Further analysis is on Y12 beams VS Y10 beams flexural strength results, some Y10 beams experimental flexural strength exhibits more strength than Y12 beams. As elaborated below.

S1-Y10 mm beam
S2-Y10 mm beam **> S3-Y12mm beam**
S4-Y10 mm beam

Further assessment of the RC beam flexural performance results in comparison with other results from previous studies in literature review of the same 12mm bar sizes and number, it is observed that the ultimate loads were in the same range of between 85 KN to 124 KN for one of the tests Table 2.3, second related test with 112.2 KN Table 2.4, and third test results of 117.6 KN Table 2.5, all of which are comparable to the current research results that ranged from 114.6 KN to 142.6 KN as per Figure 4.10.

The 4th experimental results which was for 10 mm bars gave 95 KN shown in Table 2.6 which were in range of the research experiment results of the same bars size that fell between 93KN and 131 KN as given in Figure 4.12.

The Figures 4.14 and 4.15 are meant to compare both experimental flexural strength and deign flexural strength for Y12 and Y10 RC beams. Flexural strength (N/mm2) is given by Fl/bd^2

Where **F** is ultimate load, **l** is effective length, **b** is the beam width and d is the effective beam depth**:** For Beam of S1 with F = 130.2KN,

$$Fl/bd^2 = \frac{\underline{30.2 \times 1500}}{150 \times 211^2} = \mathbf{29.24}\ N/mm^2$$

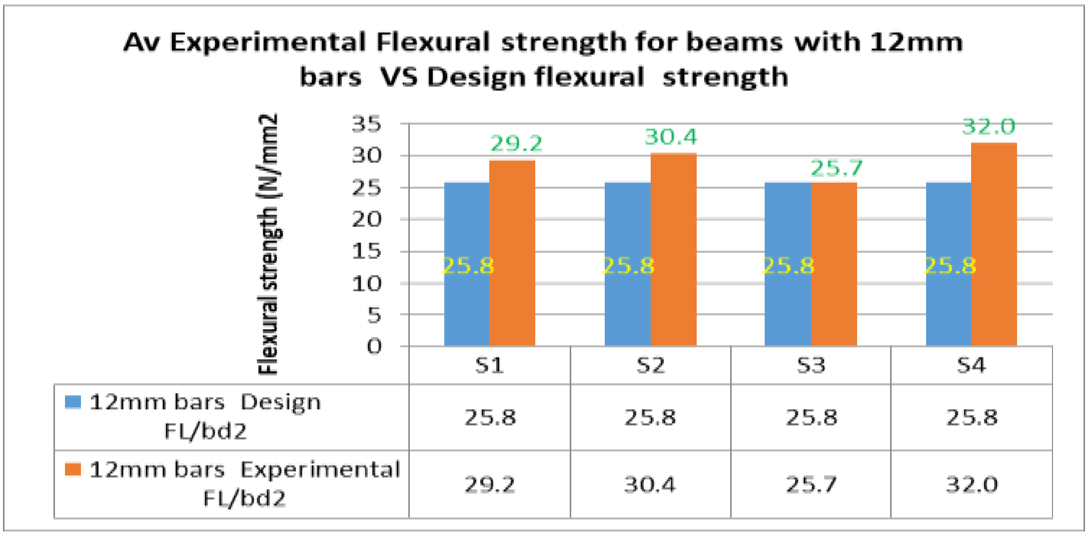
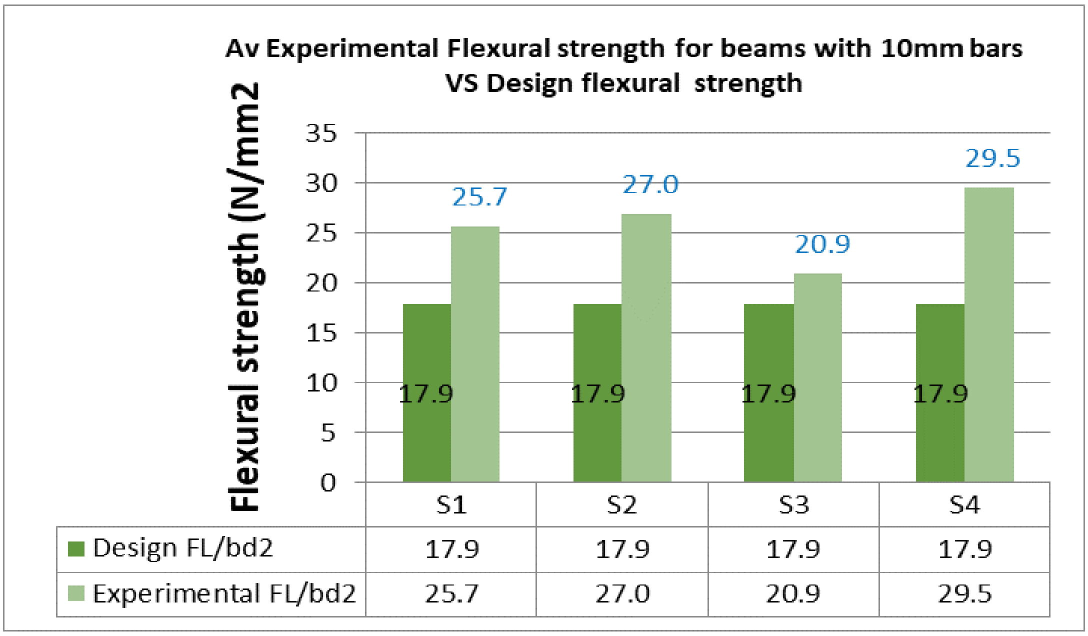


Figure 4.14: Experimental flexural strength VS flexural design strength Y 12 beams



	S1	S2	S3	S4
Design FL/bd2	17.9	17.9	17.9	17.9
Experimental FL/bd2	25.7	27.0	20.9	29.5

Figure 4.15: Experimental flexural strength results for Y 10 beams

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The main objective of this study was to assess the quality of steel reinforcing bars available in Rwanda together with their subsequent structural performance on reinforced concrete beams. From the physical verifications and experiments conducted the following conclusions were made:

a) The steel reinforcing bars' physical feature requirements such as diameter, length, ribs and labeling were met by 6 samples out of 24 putting it at 25%. The worst being S3 which fell short of all physical property requirements at 100%, this is the same brand that was found with not marks at all.

b) It was observed that yield strength of 11 samples out of 24 fell below standard code requirements, which means 45.8 % failed to meet yield strength requirements, of the failed 45.8% only 12.5% were Y12 while the remaining 87.5% were Y10.

c) Two samples out of 24 steel reinforcing bar tested failed to comply with the minimum ultimate tensile strength to yield strength ratio of 1.08 as specified by BS 4449: 1997, hence only 8.3% failed to meet the requirements.

d) Bonding characteristic requirements were met by 22 samples out of 24, only 2 samples from source 3(S3) of size 10 mm diameter failed by total breakage before being pulled out.

e) It has been concluded that despite foreign rebars preference by developers and engineers, locally made rebars have proved to bear high strength than most of them and performed well in structural elements yet less costly and hence suitable for application.

f) The Experimental flexural load of RC beam made of Y12 mm was determined to fall between 114.6 KN and 142.6 KN, compared to design load of 123.7 KN while experimental flexural strength fell between 25.7 N/mm^2 to 33.4 N/mm2 compared to design flexural strength of 25.8 N/mm^2. It observed that Source 3 samples which obtained 114.6 KN flexural load and 25.8 N/mm^2 flexural design portrays incompetency in load carrying capacity of the beam.

g) The flexural load of RC beam made of Y10 mm was found to be in range of 93 KN to 131.5 KN while their respective flexural strength ranged from 20.9 N/mm^2 to 29.5 N/mm^2 as compared to their design load of 85.8 KN and design flexural strength of 17.9 N/mm^2 respectively. All beam samples demonstrated required load carrying capacities, actually some Y10 mm beams performed better than Y 12mm beams.

5.2 Recommendations

(i) For Application

In an attempt to find solutions to problems related to substandard steel reinforcing bars which still exist at large, and to ensure that they play their role of reinforcing structures to a more reliable and stable conditions, the following recommendations were made:

(a) From the research made and analysis of test results obtained, it is proved that the steel reinforcing bars that are not traceable exhibit poor strength results, it is therefore recommended that rebars without standard labelling be prohibited from both importation and local production and completely be banned from being sold on local market.

(b) From literature review recycling of metal scraps in steel making is almost inevitable, therefore well defined systems should be put in place for effective quality control of scraps before being used in milling of steel reinforcing bars. The associations of metal scrap sellers should be formed and held accountable for quality in addition to RSB enforcement of control measures.

(c) The engineering material properties should be emphasized on while purchasing rebars for a sound and durable reinforced concrete structure, through inspection of importation certificates. The data on the certificates should be reaffirmed through laboratory tests before being put into use to compare with design values otherwise design would bears no justifiable meaning.

(d) It is recommended that the era of foreign steel bars' preference while undermining local production be revisited in the spirit of promoting made- in-Rwanda, as they have proved to meet standard requirements and even performing well in structural members yet with a reasonably low cost.

(e) It is recommended that tight regulating mechanisms be put in place to control infiltration of substandard steel reinforcing bars on local market.

(ii) For Further Research

(f) Further research is recommended on different sizes of steel bars available in Rwanda and their performance structural behaviour in other structural members like slabs and columns.

REFERENCES

Abdelhamid, C, Mourad, S. M., & Khan, M. I. (2016). Flexural behavior of beams reinforced with steel bars exceeding the nominal yield strength. *Latin American Journal of Solids and Structures*, *13*(5), 945-963.

Adetoro A. E & Oladapo A.S. (2017). Assessment of Suitability of Selected Reinforcing Bars Used for Construction in Nigeria. *Journal of Multidisciplinary Engineering Science and Technology (JMEST), 4*(5), 7308-7313.

Akintoye, O., Fapohunda, C., & Dixon, O. (2013). Effects of source of reinforcement on microstructure and Strength characteristics of reinforced concrete beams. *Civil and Environmental Research*, *3*, 26-36.

Alhassan, M., Al-Rousan, R., & Ababneh, A. (2017). Flexural behavior of lightweight concrete beams encompassing various dosages of macro synthetic fibers and steel ratios. *Case studies in construction materials*, *7*, 280-293.

American Standard of Testing Materials (1979) *ASTM A615/A615M-16 Standard Specification For Deformed And Plain Carbon-Steel Bars For Concrete Reinforcement,* Washington- D.C: American Standard of Testing Materials.

AS/NZS 4671 (2001). *Steel for the reinforcement of concrete- standard dimensions, weight and properties.* New Zealand: Standards Australia/Standards New Zealand.

Australian Reinforcing Company (ARC) (2010). *Reinforcement Handbook,* (Sixth Edition). Australia: Australian Reinforcing Company (ARC).

Balamoorthi, K. (2017). An Experimental Study on Flexural Behaviour of Reinforced concrete beam by varying the grade of concrete in tension zone: International Journal of Civil Engineering, *4*(5), 7308-7313.

Balamurugan, R. (2017). An experimental study on flexural behaviour of reinforced sandwich beam by varying the aggregate in tension zone. *SSRG International journal of civil engineering*, 2348-8352.

Balogun, S. (2009). Challenges of Producing Quality Construction Steel Bars in West Africa: Case Study of Nigeria Steel Industry, *Journal of Minerals & Materials Characterization & Engineering, 8*(4), 283-292.

Bamigboye, G. O., Olaniyi, O. A., Olukanni, D. O., Ede, A. N., & Akinwumi, I. I. (2017). Diameter inconsistency, strength and corrosion characteristics of locally-produced and imported steel reinforcing bars in Ilorin, Nigeria. In *International Journal of Engineering Research in Africa, 29,* 90-97.

Basu, P.C. (2004). Characterisation of steel reinforcement for RC structures: An overview and related issues, The *Indian Concrete Journal, 78*(1), 9-30.

Brindha, D. & Nagan, S. (2010). *Flexural strength of beams incorporating copper slag as partial replacement of fine aggregate in concrete.* Madurai. India: Thiagarajar College of Engineering.

BS 4449 (2005). *Steel for the reinforcement of concrete, weldable reinforcing steel bar, coil and decoiled product, specification,* London: British Standard Institution.

BS 4449 (2009). *Steel for the reinforcement of concrete, weldable reinforcing steel bar, coil and decoiled product, specification*: British Standard Institution, London British Standard Institution.

BS 4449 (1997). *Specification for carbon steel bars for the reinforcement of concrete.* London: British Standards Board.

BS 8110 (1997). *Structural use of concrete Part 1. code of practice for design and construction, British Standard Institution*, London: British Standard Institution.

Bureau of Indian standards (2008). *High strength deformed steel bars and wires for concrete reinforcement specification* (fourth revision), Manak Bhavan, 9 Bahdur- New Delhi: Bureau of Indian standards.

Carpinteri, A., Carmona, J. R., & Ventura, G. (2011). Failure Mode Transitions in Reinforced Concrete BeamsPart 1: Theoretical model. *ACI Structural Journal. 108,* 277-85.

Chanakya. A (2009). *Design of structural elements, Concrete, steelwork, masonry and timber designs to British standards and Eurocodes*. London: Taylor and Francis.

CIVL 112 (2018). *Strength in reinforced concrete beams: Civil engineering*. US: University of Mephis.

Construction Industry Development Board –CIDB (2015). *Quality assessment system for building construction works*. (second edition)**.** Malaysia: Lembaga Pembangunan Industries Pembinaan

Department of building and housing (2005). *Report on grade 500E steel reinforcement,* Wallington, New Zealand: Department of building and housing.

Draycott, T (1999). *Structural Elements design manual.*, Oxford Butterworth. Hinemann.

Durocrete Engineering Service Pvt Ltd (2009). *Construction Quality assurance: Durocrete Mix Design Manual*. Pune - 411051, Maharashtra, India: Durocrete Engineering Service Pvt Ltd

Ejeh. S.P.I, & Jibrin. M. U (2012). Tensile Tests on Reinforcing Steel Bars in the Nigerian Construction Industry, *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) 4*(2), 06-12 .

Eskenati, A. R & Varasteh, P. H (2015). Premature Failure and its Prevention in Flexural Beams Retrofitted by GFRP Fibers: *Journal of the Institute of Engineering, 11*(1), 12-19.

Farrukh, H & Mohd, A (2011). B*asic mechanics and Science of Materials.* Engineering practical book vol II: Dwarka, New Delhi: Educreation publishing.

Figueroa, P,H F, (2014). *Strategies to Reduce the Risk of Building Collapse in Developing Countries.* Unpublished PhD Thesis, Mellon: Carnegie Mellon University.

Ghoneim. M, & El-Mihilmy. M (2008). *Design reinforced concrete structures,* (second edition), Egypt: Cairo University.

GoHK, Construction Standard-CS2 (2012). *Steel Reinforcing Bars for the Reinforcement of Concrete*, Homantin, Kowloon, Hong Kong: GoHK, Construction Standard-CS2.

GoHK, Construction Standard-CS2 (2018). *Steel Reinforcing Bars for the Reinforcement of Concrete,* Homantin, Kowloon, Hong Kong: GoHK, Construction Standard-CS2.

Hong Kong institute of vocational education (2014). *Conc 4332 reinforced concrete design formulae for bending Ch 2*. Hong Kong: Hong Kong institute of vocational education.

IS 1786 (2008). *High strength deformed steel bars and wires for concrete reinforcement- [CED 54*: Concrete Reinforcement. New Delhi: Bureau of Indian Standard.

IS 456 (2000). *Plain and Reinforced Concrete - Code of Practice*; CED 2: Cement and Concrete. New Delhi: Bureau of Indian Standard.

ISO 6935-2 (2015). *Steel for the reinforcement of concrete*, Part 2: Ribbed bars, Geneva: International Organization for Standardization.

Jibrin, M. U., & Ejeh, S. P. (2013). Chemical composition of reinforcing steel bars in the Nigerian construction industry. *Int. J. of Civil & Environmental Eng. IJCEE-IJENS*, *13*(01), 1216606-1301.

Kant, N. (2016). *Effects of Nitrogen on Mechnical Properties, microstructure and weldability of low Carbon Micro Alloyed Structural Steel*. India: Indian Institute of welding.

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

Kesegić, I., Varevac, D., & Morić, D. (2009). Deflection of over-reinforced concrete beams: comparison of analytical, numerical and experimental results. *Tehnički vjesnik*, *16*(1), 35-40.

Kristiawan, S., Supriyadi, A., Sangadji, S., & Santosa, D. (2017). Cracking behaviour and its effect on the deflection of patched-reinforced concrete beam under flexural loading. In *MATEC Web of Conferences* (Vol. 138, p. 02021). EDP Sciences.

Kulkarni, S. K., Shiyekar, M. R., & Wagh, B. (2012). Elastic properties of RCC under flexural loading. *International Journal of Modern Engineering Research (IJMER)*, *2*, 4022-4025.

Kumar, D.S &Rajkumar, R (2016). Experimental Investigation on Flexural Behavior of Concrete Beam with Glass Fibre Reinforced Polymer Rebar as Internal Reinforcement, *Int. J. Chem. Sci.: 14*(S1), 319-329.

Kumar, G. N., & Sundaravadivelu, K. (2017). Experimental Study On Flexural Behaviour Of Beams Reinforced With GFRP Rebars. *Earth and Environmental Science*, *80*, 012027.

Kumaraswamy. S (2013). Experimental study on strength and flexural behaviour of reinforced concrete beams using Deflected structural steel as reinforcement: IOSR *Journal of Mechanical and Civil Engineering, 6*(1), 38-43.

Kwan, A. K. H., Ho, J. C. M., & Pam, H. J. (2002). Flexural strength and ductility of reinforced concrete beams. *Proceedings of the Institution of Civil Engineers-Structures and Buildings*, *152*(4), 361-369.

Kwan, A. K. H., Ho, J. C. M., & Pam, H. J. (2004). Effects of concrete grade and steel yield strength on flexural ductility of reinforced concrete beams. *Australian Journal of Structural Engineering*, *5*(2), 1-20.

Libor, P, Bílek, V., Dědečková, L., & Smutný, J. (2012). *Monitoring four point bending of concrete beams by acoustic emission method.* Czech Republic: Brno university of technology.

Madias, J., Wright, M., Behr, O. G., & Valladares, V. (2017). Analysis of international standards on concrete reinforcing steel bar. *AISTech 2017 Proceedings*.

Malay, S. (2019) Factors affecting the durability of concrete: Civil Engineering. Retrieved from: **https://civilnoteppt.com/factors-affecting-the-durability-of-concrete**

Marsh, B K (1997). Building research establishment: Design of normal concrete mixes (second edition), London: BRE publications, construction research communications Ltd.

Martin, J.S. (2006). *An Experimental Investigation of Bond in Reinforced Concrete*. Unpublished MSc thesis, Washington: University of Washington.

Mita, A. Z. & Sunitha, A D. (2016). Experimental Analysis of Flexural Behaviour and Crack Pattern of RCC Composite Beam. *International Journal of Science Technology & Engineering (IJSTE), 3*(3), 234-243.

MMFX (2011). *Steel corporation of America, Quality assurance manual* (5th Edition). USA: MMFX

Mohd. A Mallick, J., & Hasan, M. A. (2014). A study of factors affecting the flexural tensile strength of concrete, New York: Elsevier ltd.

Mourad, S., Charif, A., & Khan, M. I. (2014). Flexural behavior of RC Beams with local steel-experimental investigation. In *International Conference on Construction Materials and Structures*, 24-26.

Munyazikwiye, B. (2010). *Investigation on Characterization and Variability of Mechanical Properties of Reinforcing Steel Bars made from Scrap*. Unpublished MSc thesis, Juja: Jomo Kenyatta University of Agriculture and Technology.

Mwasame, G, (2012). Safety and structural reliability of reinforced concrete buildings in Kenya. *International Journal of Disaster Management and Risk Reduction*, *4(*2), 342- 349.

Nassaka, F (2016) Collapsing buildings: Engineers vow tough action, Retrieved from: https://www. independent. co.ug/collapsing-buildings-engineers-vow-tough-action/,

National Institute of Standard and Technology -NIST (2014). *Use of High-Strength Reinforcement in Earthquake-Resistant Concrete Structures*, U.S. Department of Commerce, Engineering Laboratory Gaithersburg.

National Institute of Standard and Technology –NIST, (2001). *Strength and Ductility of concrete beams reinforced with carbon FRP and stee*l, U.S. Gaithersburg: National Institute of Standard and Technology –NIST.

Nkem. A E., Egunjobi, E. O., Bamigboye, G., & Ogundeji, J. (2015). Assessment of quality of steel reinforcing bars used in Lagos, Nigeria. *International Research Journal of Innovative Engineering*, *1*(3).

Nkem.A E., Olofinnade, O. M., & Joshua, O. (2014). Experimental investigation of yield strengths of steel reinforcing bars used in Nigerian concrete structures. *Experimental Investigation of Yield Strengths of Steel Reinforcing Bars Used in Nigerian Concrete Structures*, *5*(4), 76-83.

Oluwafemi, L. Adekoya, L. O., & Loto, C. A. (2018). Evaluation of surface geometries and physical properties of concrete reinforcement steel rods rolled in Nigeria. *Case studies in construction materials*, *8*, 150-159.

Opeyemi, J, Olusola, K. O., Oyeyemi, K. D., Ogunde, A. O., Amusan, L. M., Nduka, D. O., & Abuka-Joshua, J. (2018). Data of the properties of rebar steel brands in Lagos, Nigerian market used in reinforced concrete applications. *Data in brief*, *17*, 1428-1431.

Opeyemi, J. Olusola, K. O., Ayegba, C., & Yusuf, A. I. (2013). Assessment of the quality steel reinforcement bars available in Nigerian market. In *AEI 2013: Building Solutions for Architectural Engineering* (pp. 296-305).

Ramsdale, R. (2006). Engineer's Handbook: Engineering material properties. Retrieved from: http://www.engineershandbook.com/ Materials/ mechanical.htmd

Rashedul, K. & Mashfiqul, I. (2014). Bond stress behavior between concrete and steel rebar: Critical investigation of pull-out test via Finite Element Modeling**.** *International Journal of Civil and Structural Engineering, 5*(1), 80 – 90.

RS EAS- 412-2 (2014). *Steel for the reinforcement of concrete — Part 2*: Ribbed bars, Kigali: Rwanda Bureau of Standards.

Rubaratuka, I.A. (2013). Challenges of the Quality of Reinforced Concrete Buildings In Dar es Salaam, *International Journal of Engineering Research & Technology, 2*(12).

Russel, O.A. & Asamoah, M.A. (2016). *Evaluation of Flexural Strength of Reinforced Concrete beams made from phyllite aggregates*. Kumasi, Ghana: Kwame Nkrumah University of Science and Technology.

Sakrani, S. (2012). *Material science SSP 2412: Mechanical properties and testing*, Malaysia: University of technology.

Salman, A., & Djavanroodi, F. (2018, April). Variability of chemical analysis of reinforcing bar produced in Saudi Arabia. In *IOP Conference Series: Materials Science and Engineering*.

Samsudi, B S. (2011). *Mechanical properties and testing: materials science* (SSP 2412). Malaysia: Science and Education.

Sasikala, T., Vijayan, L., Rishikanth, R., Raguvaran, T., & Raja, R. (2018). Experimental Investigation on Flexural Behaviour of Rcc Beam With Gfrp Sheets As A Wrapping Material. *Indian Journal of Scientific Research*, 149-152.

Senfuka, C Senfuka, C., Kirabira, J. B., & Byauhanga, J. K. (2013). The Concrete Reinforcing Value of Recycled Steel Bars in Uganda., *IOSR Journal of Engineering, 3*(1), 15-19.

Singh, B. & Kaushik. S.K. (2002). Influence of steel-making processes on the quality of reinforcement, The Indian Concrete Journal, Elsevier Science Ltd, *1*(1), 1-8

Spencer, C. (2016). Five reasons why buildings collapse: BBC News, Retrieved from: https://www.bbc.com/news/world-africa-36205324.

Tabaro, C (2013). *Four killed, several injured in Nyagatare building collapse*. The Kigali: New Times-Rwanda.

Taghried, I M A Abu-Elgasim, E., Hamdan, R. M., Abdelgadir, I. A. M., Alahmar, I. H. B., & Aldar, M. A. T. (2017). Quality Evaluation of Steel Reinforcement

Bars in Khartoum State. Red sea university Journal of Basic and Applied Science, 2(1).

Tejaswi, S., & Ram, J. E. (2015). Flexural Behavior of RCC Beams. *International Journal of Innovations Research in Engineering and Technology*, *5*, 220-224.

UK CARES part 2 (2011). Guide to Reinforcing Steels Sevenoaks: UK CARES

UK CARES part 3 (2011). *Guide to Reinforcing Steels*, Sevenoaks: UK CARES

APPENDICES

Appendix I: Concrete Mix Design Procedure

Step 0 is to define characteristics of materials to be used in the required concrete. Maximum water content, type of cement and its grade, compressive strength of concrete at 28 days, Maximum coarse aggregate size and their type whether crushed or not, expected percentage of fine aggregate passing 600 µ sieve, workability slump, and setting preliminary data:

Preliminary Data:

- Plastic concrete to a minimum slump of 50 mm

-Maximum water cement ratio of 0.5

-Minimum compressive strength to 30 N/mm^2 at 28 days of complete curing,

- Standard deviation S ……………………..10

-Constant K

The design followed the following steps:

Determining mean target strength f_t based on the predetermined compressive strength f_{ck} at 28 days and standard deviation s:

Using standard formula: $f_t = f_{ck} + 1.65$ S………………………………,,,,,,,,,(A.1)

1st Step: Selection of target water/cement ratio

The standard formula for calculating target water/cement ratio involves two stages:

(i) Margin (M) = k x s………………………………,,,,,,,,,,,,,,,,,,,,,,,,,,..,(A.2)

Where:

M = the margin; k is risk factor (constant)= 'percentage defectives' permitted below the characteristic strength and can be obtained from normal distribution curve. *s* = the standard deviation.

(ii) find Target mean strength (fm)= fc+ k s ………………………………..(A.3)

Where: *f*c= the earlier specified characteristic strength at 28 days

ks= the margin, which is the product of:

Having obtained M= ks from eqn 3.2, and knowing the value of **fc** then value **f**m can be obtained from eqn 3.3, We can now obtain approximate strength of concrete from standard graph for the strength of a mix made with a free-water/cement ratio of 0.5 according to the specified age, the strength class of the cement and the aggregate to be used. Assuming cement was 42.5 grade with crushed coarse aggregates.

Then we can obtain approximate strength of concrete from **as 49N/mm2.**

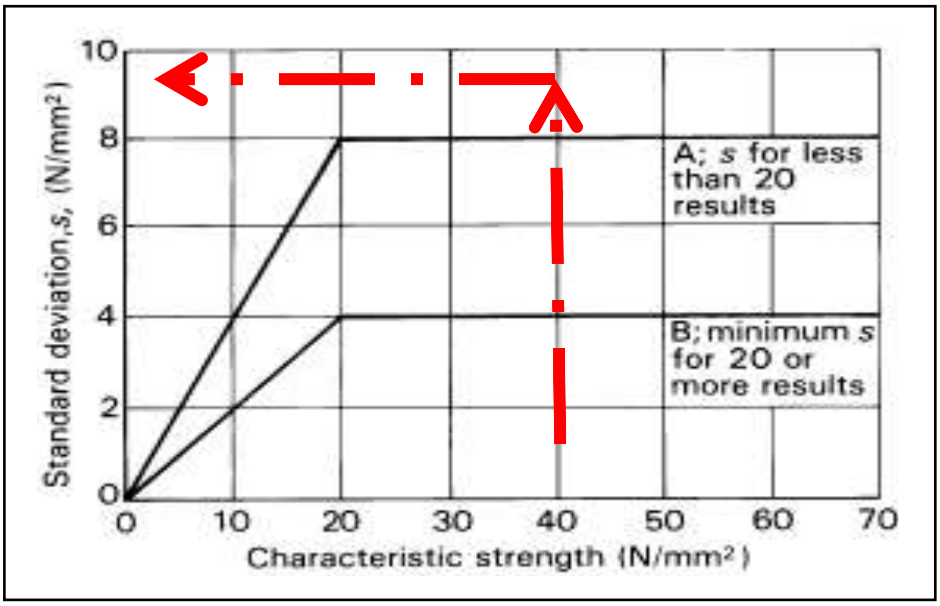


Figure A1: Standard graph from DOE for concrete standard deviation

Table. A1: Standard table from DEO for estimating concrete strengths

Cement strength class	Type of coarse aggregate	Compressive strengths (N/mm^2) Age (days) 3	7	28	91
42.5	Uncrushed	22	30	42	49
	Crushed	27	36	49	56
52.5	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

Using the data:

Cement grade 42.5,

Crushed aggregates,

This obtained strength value is then plotted on and the free-water/cement ratio can then be read from the abscissa. From the above assumption of values, starting from 0.5 cement water ratio earlier specified and target mean strength calculated.

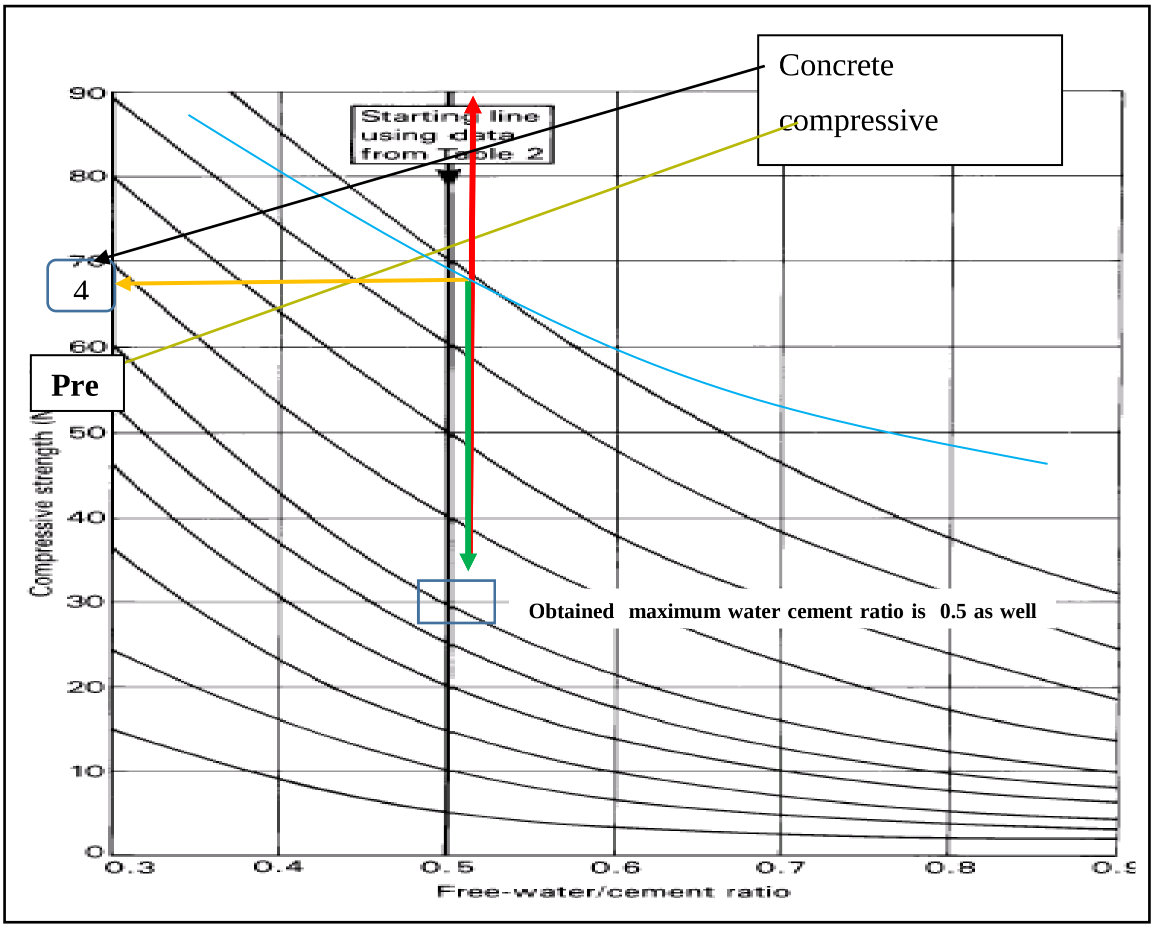


Figure A2: Standard graph for estimation free-water/cement ratio

Compare this value at green arrow with maximum free-water/cement ratio which 0.5 and the lower of these two values used. Incidentally they happen to be the same (0.5).

2nd Step: Selection of free-water content

Consists of determining the free-water content from standard depending upon the type and maximum size of the aggregate to give a concrete of the specified slump.

Table A2: Determination of the free-water content (kg/m3)

Slump (mm)		0–10	10–30	30–60	60–180
Vebe time (s)		>12	6–12	3–6	0–3
Maximum size of aggregate (mm)	Type of aggregate				
10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

Free water content is selected based on the:

1. Maximum size of aggregates (msa) used 20, crushed type

2. The pre-set plastic concrete target slump 50mm which is between 30 and 60mm indicated above

From the table 3.2, then we get free water content as 210 kg/m3

3rd Step: Determination of cement content

Cement content = free-water content (Kg/m3) / free-water/cement ratio

From the above assumed results: Cement content = 210÷ 0.5 = 420 kg/m3, approximately 8 bags of cement/ m3. The result should be checked against any maximum or minimum value that may be specified.

4th Step: Determination of total aggregate content

Estimate of the density of the fully compacted concrete which is obtained from Figure3.3. If no information is available assume a value of 2.6 for uncrushed aggregate and 2.7 for crushed aggregate, then precisely plot on standard graph to obtain approximate wet density of concrete mix as shown below on the standard graph with the help of two curves of relative density of combined aggregate on the graph, basing on used aggregate whether crushed, plotting from free water content obtained from the standard table then you get corresponding wet density of concrete mix. From free-water content of 210 Kg/m3, then to crushed curve of 2.7 the corresponding density of wet concrete mix as red from graph is 2400 kg/m3.

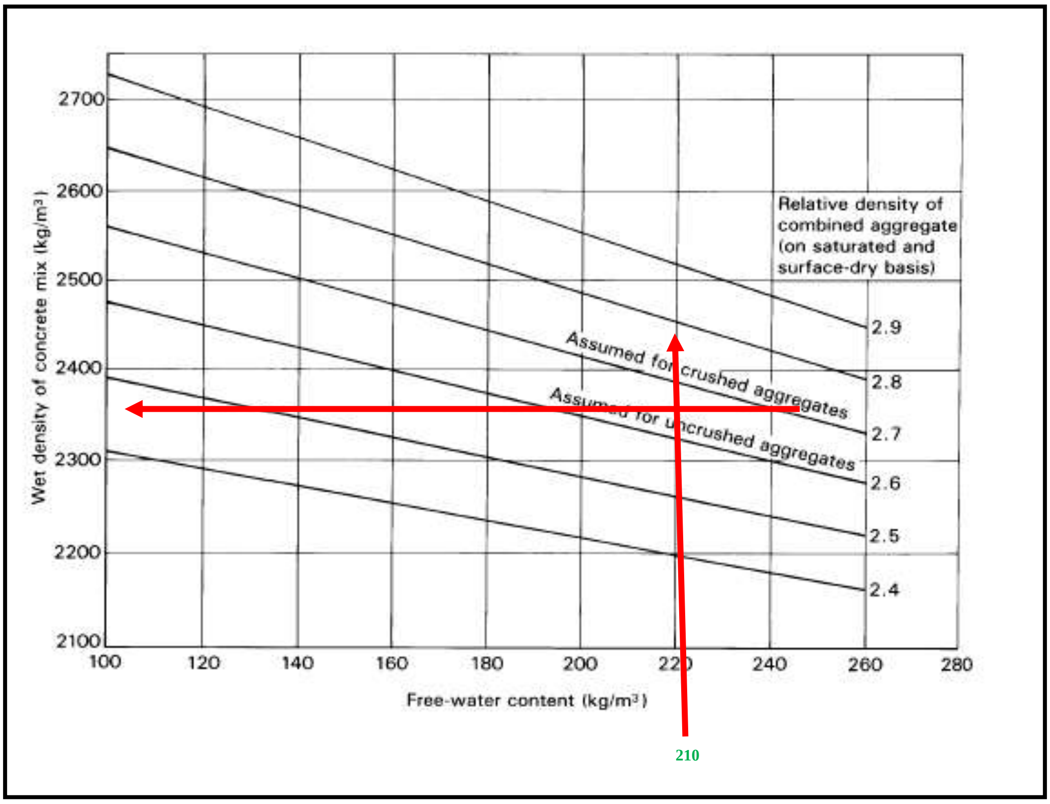


Figure A3: Estimation of density of fully compacted wet concrete

Total aggregate content is determined after obtaining density of wet concrete mix, density of water and density of cement.

Wet density of concrete (kg/m3) = Cement content (kg/m3) + Total aggregates + water**.**

Hence: Total aggregate content = wet density of concrete (D) kg/m3 — cement content (C) kg/m3 - free-water content (W) kg/m3.

Wet density of concrete 2400kg/m3 -420 kg/m3 – 210 kg/m3 = **1,770** kg/m3.

5th Step: Selection of fine and coarse aggregate contents

Having obtained total aggregate, next is to get the quantities of fine aggregates and coarse aggregate separate. Fine aggregates are obtained from Figure 3,7 basing on pre determined Concrete slump, Percentage passing in 600µ sieve and maximum coarse aggregate size and the free cement ratio. Concrete slump is 50 mm. Percentage passing in 600µ sieve is 70%, maximum coarse aggregate size is 20 mm and free cement ratio of 0.49, we can now plot and obtain proportion of fine aggregate from Figure 3.7.

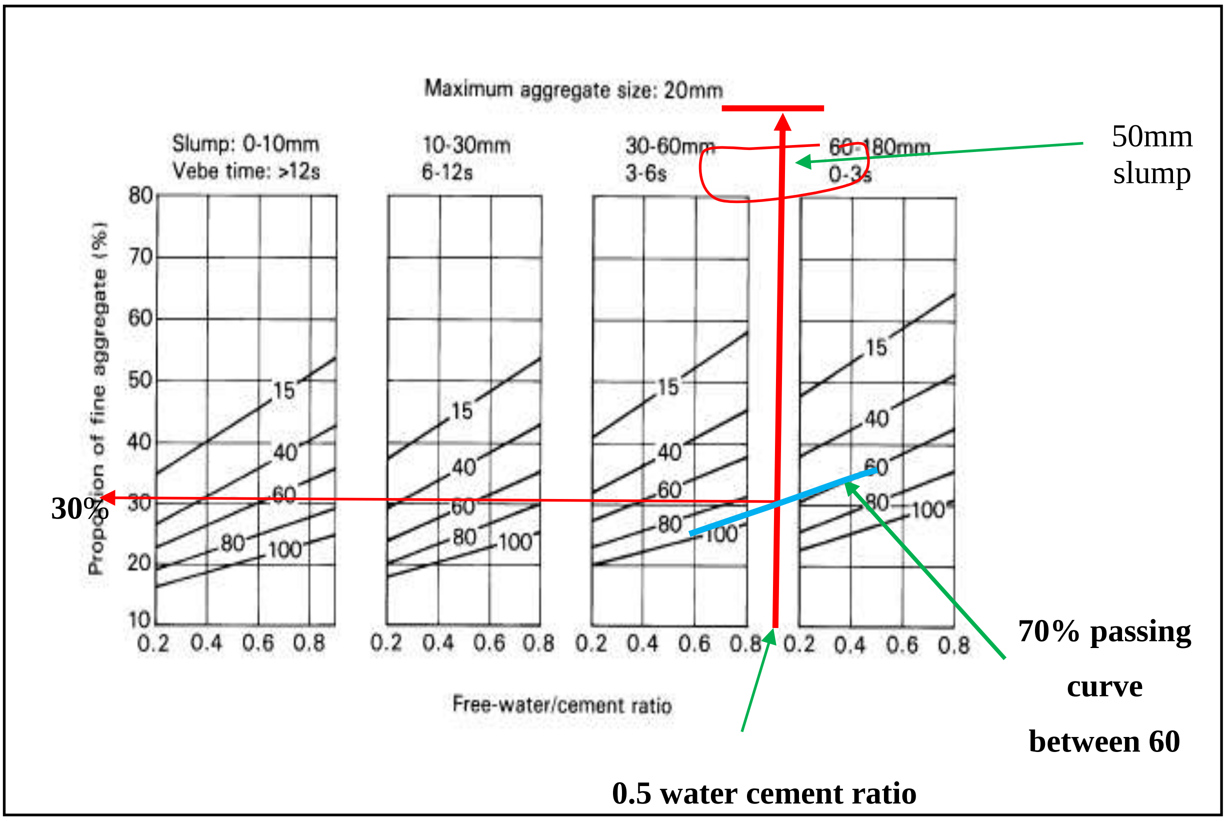


Figure A4: Estimation of fine aggregate according to percentage passing 600µ

Fine aggregate content = (total aggregate content) x (proportion of fines)

Coarse aggregate content = (total aggregate content) - (fine aggregate content)

Having got 30% as the fine aggregate percentage, knowing Total aggregate content as 1,770 kg/m3, this implies that:

Fine aggregate = 30 /100x 1,770 = 531 Kg/m3.

Coarse aggregate content = 1,770 - 531 = 1,239 Kg/m3

Appendix II: Table B 1: Rebars Tensile Strength Test Results

Source	Bar size, mm	Weight (Kg)	Length (m)	Weight per meter run	Standard Ms/mtr	Cross section area, mm2	Standard Crs sect area (mm2)	Yield load, KN	Ultimate tensile load, KN	Yield stress, N/mm2	ultimate tensile stress, N/mm2	stress ratio Rm/Re	% Elongation
	10	0.30	0.5	0.60	0.616	76.81	78.5	35.9	43	468.0	560.00	1.20	18.4
	10	0.32	0.5	0.63	0.616	80.25	78.5	31.7	43.5	395.0	542.50	1.37	17.5
	10	0.31	0.5	0.63	0.616	80.00	78.5	31.8	43.3	396.9	551.59	1.39	17.7
	12	0.44	0.5	0.87	0.888	111.08	113.1	67.9	77.9	611.5	689.30	1.13	17.5
	12	0.42	0.5	0.84	0.888	107.01	113.1	58.0	66.9	542.0	591.80	1.09	17.8
S1	12	0.42	0.5	0.83	0.888	106.28	113.1	54.1	73.1	509.0	688.00	1.35	17.5
	10	0.32	0.5	0.63	0.616	80.40	78.5	31.4	43.6	390.0	543.00	1.39	17
	10	0.32	0.5	0.64	0.616	81.53	78.5	35.6	43.2	436.5	550.32	1.26	17.4
	10	0.32	0.5	0.64	0.616	81.53	78.5	35.8	45.2	439.3	575.80	1.31	17.4
	12	0.45	0.5	0.90	0.888	114.60	113.1	60.5	72.3	527.9	685.00	1.30	18.7
	12	0.45	0.5	0.90	0.888	114.60	113.1	58.9	67.9	513.7	698.00	1.36	19.1
S2	12	0.43	0.5	0.87	0.888	110.25	113.1	63.6	74.9	577.0	680.00	1.18	19.2
	10	0.25	0.5	0.50	0.616	64.12	78.5	23.1	35.28	361.0	550.00	1.52	18
	10	0.24	0.5	0.48	0.616	60.60	78.5	21.7	36.2	358.5	460.80	1.28	23
	10	0.24	0.5	0.48	0.616	61.70	78.5	22.6	35.3	365.9	480.00	1.31	21
	12	0.31	0.5	0.63	0.888	80.00	113.1	35.0	47.2	437.5	562.10	1.28	19.2
S3	12	0.36	0.5	0.72	0.888	91.46	113.1	42.0	55.7	459.0	492.30	1.07	18.5

	12	0.39	0.5	0.78	0.888	99.70	113.1	36.0	53.2	361.0	534.00	1.48	19.2
	10	0.30	0.5	0.60	0.616	76.56	78.5	42.5	50.3	555.0	651.00	1.17	25.4
	10	0.30	0.5	0.61	0.616	77.20	78.5	42.1	49.7	545.4	630.30	1.16	25
	10	0.31	0.5	0.61	0.616	78.22	78.5	47.0	53	600.9	675.30	1.12	25
	12	0.44	0.5	0.87	0.888	110.83	113.1	68.0	77.6	613.6	686.30	1.12	24.2
	12	0.42	0.5	0.84	0.888	107.62	113.1	58.7	79	545.0	698.00	1.28	25
S4	12	0.43	0.5	0.85	0.888	108.28	113.1	62.4	78.1	576.3	690.00	1.20	23.9

The highlighted in red are yield strength that did not meet the 460 N/mm2 code requirements

Appendix III: Table C.1: Rebars Cost Comparison

	12mm bar diameter				**10mm bar diameter**			
Source	S1	S2	S3	S4	S1	S2	S3	S4
Cost/m frw	708	583	567	858	483	458	400	550
Av Re (N/mm^2)	554	540	419	578	420	422	362	567
Av Rm	656	688	529	691	551	556	497	652

Appendix IV: Table D.1: Chemical Composition Test Results

Tested ingradients	BIS 4449:1997 and RS EAS 412-2: 2014 Requirements	Source of the sample and bar diameter in mm							
		S1		S2		S3		S4	
		12	10	12	10	12	10	12	10
Carbon	≤ 0.25	0.14	0.239	0.189	0.189	0.178	0.157	0.146	0.159
Sulphur	≤ 0.05	0.0182	0.0168	0.0346	0.0346	0.0316	0.0287	0.0211	0.0138
Phosphorus	≤ 0.05	0.0299	0.0301	0.0441	0.0441	0.0432	0.0406	0.037	0.0269
Nitrogen	≤ 0.012	0.0628	0.0619	0.0786	0.0786	0.0761	0.0843	0.103	0.0872
C EV	≤ 0.51	0.308		0.33		0.31		0.311	

Appendix V: Table E.1: Different Loads' Effects of Different RC Beam Bar Sizes

	Load S1 (12mm Bar)	**Load S1 (10mm Bar)**	**Load S2(12mm Bar)**	**Load S2 (10mm Bar)**	**Load S3 (12mm Bar)**	Load S3 (10mm Bar)	**Load S4 (12mm Bar)**	**Load S4 (10mm Bar)**
Pcr	95.50	63.0	96.2	63.3	68.8	51.5	107.5	73.2
Py	127.30	103.3	131.5	105.3	103.7	82.5	134.9	123.9
Pu	130.20	114.4	135.3	120.0	114.6	93.0	142.6	131.5

Appendix VI: Table F.1: RC Beams Y12-10mm Experimental Flexural VS Flexural design strength

(i) Y 12 mm beams

Source	F(KN)		Ult. Load F	L	FL	BD2	Exp FL/BD2 (N/mm2)	Designed FL/BD2 (N/mm2)
S1	130.2	1000	130,200	1500	195,300,000	6678150	**29.24**	**25.8**
S2	135.3	1000	135,300	1500	202,950,000	6678150	**30.39**	
S3	114.6	1000	114,600	1500	171,900,000	6678150	**25.74**	
S4	142.6	1000	142,590	1500	213,885,000	6678150	**32.03**	

(ii) Y 10 mm beams

	F(KN)		F (N)	L	FL	BD2	Exp FL/BD2 (N/mm2	Designed FL/BD2 (N/mm2)
S1	114.4	1000	114,400	1,500	171,600,000	6678150	**25.70**	
S2	120.0	1000	120,000	1,500	180,000,000	6678150	**26.95**	
S3	93.0	1000	93,000	1,500	139,500,000	6678150	**20.89**	
S4	131.5	1000	131,527	1,500	197,290,000	6678150	**29.54**	**17.9**