

**MODELS FOR PREDICTING THE MECHANICAL PROPERTIES OF ROLLED
RIBBED MEDIUM CARBON STEEL.**

BY

ADEBAYO ABDULLAHI OLAWALE

(MME/95/6008)



**DEPARTMENT OF METALLURGICAL AND MATERIALS ENGINEERING,
THE FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE, NIGERIA.**

DECEMBER, 2010.

APPROVAL



**MODELS FOR PREDICTING THE MECHANICAL PROPERTIES OF ROLLED
RIBBED MEDIUM CARBON STEEL.**

BY

ADEBAYO ABDULLAHI OLAWALE

(MME/95/6008)

A THESIS IN

DEPARTMENT OF METALLURGICAL AND MATERIALS ENGINEERING

SUBMITTED TO

THE DEPARTMENT OF METALLURGICAL AND MATERIALS

ENGINEERING,

THE SCHOOL OF POSTGRADUATE STUDIES,

IN PARTIAL FULFILMENT FOR THE REQUIREMENT FOR THE AWARD OF

MASTER OF ENGINEERING (M. ENG.)

IN DEPARTMENT OF METALLURGICAL AND MATERIALS ENGINEERING,

THE FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE, NIGERIA.

DECEMBER, 2010.

CERTIFICATION

A. (By the Student):

This work has not been presented elsewhere for the award of a degree, or any other purpose.

Candidate's Name: **Engr. Adebayo, Abdullahi Olawale**

Signature: 

Date: 22nd DECEMBER, 2010

B. (By the Supervisor):

I certify that this work has been carried out by Engr. Adebayo, Abdullahi Olawale in the Department of Metallurgical and Materials Engineering of The Federal University of Technology, Akure. Ondo State.

Supervisor's Name: **Dr. A. Oyetunji**

Signature: 

Date: 06th January, 2011



ACKNOWLEDGEMENT

I give glory and thanks to almighty Allah, the first without a beginning and the last without an end, the Lord of the worlds for making this struggle a reality.

My whole-hearted appreciation goes to my project supervisor - Engr. Dr. Akinlabi Oyetunji for his brotherly and professionally inestimable contributions that saw this project through. He had indeed contributed morally, academically and financially towards the success of the project. I am very grateful and say Jazakumllahu khayran.

I owe a debt of gratitude to my HOD, Engr. Prof. B. O. Adewuyi for ensuring the success of the programme. My appreciation extends to Prof. J. O Borode (the PG coordinator for the Department), Engr. Dr. J. A. Omotoyinbo including our "BABA" in the Department, Engr. Dr. J. O. T. Adewara. I am also grateful to Engr. Dr. K. K. Alaneme for his advice. My good friends - Mr. Abel A. Barnabas, Mr. Segun and all the staff of the department of Metallurgical and Materials Engineering, FUTA, I say thanks to you all.

Furthermore, I will like to acknowledge the contributions of the following individuals: Messer Abdul-Ganiyy Kolawole, Nuhu Awwal and Cyril all at Ajaokuta Steel Company Limited Ajaokuta, Kogi State. I also appreciate the effort of Mr. Ezeghare of Delta Steel Company Aladja, and Mr. Olasupo Ogundare of EMDI, Akure. Also to, Mr. Tirmidhi (Abu Abdul-Hameed), Bro. Kamil Balogun, including my colleague, Mr. Opaluwa Idoko for their assistance and contributions on the project. The encouragement and financial supports of Alhaji Dr. Abdulazeez Apempe and his wife, Mrs Ameenah Abdulazeez is recognized and appreciated.

My gratitude goes to my soul-mate, Hajia Samiat K. Abdulkareem (Adebayo), an inestimable golden jewelry that is very rare to come by for her immense contributions and my children- Maryam, Khadeejah and Abdurrahman and Aishah. The assistance and patience of my parents, Alhaji and Mrs Tijani Adebayo are equally appreciated. I also say thank you to my brothers: Bashir (Abu Abdul-Basit), Sulayman (Abu Aishah) and my sister- Mujeedah (Umu Aishah) including all other members of the family that contributed in one way or the other.

Finally, I once again thank Allah and everyone who has contributed positively in one way or the other towards the success and timely completion of the programme. May Allah (SWT) in HIS infinite mercy reward you all abundantly. (Ameen).



DEDICATION

This work is dedicated to:

Allah the almighty, my beloved parents and late brother, Mr. Taofeeq Adebayo.



ABSTRACT

The impact toughness; tensile properties - tensile strength at maximum load, tensile strength at break and yield strength; as well as hardness property of medium carbon steels rolled from inland rolling mills (Ajaokuta Steel Company Limited (ASCL) and Delta Steel Company (DSC)) were determined experimentally and quantitatively in this research.

The experimental data obtained were used to develop models with and without iron which is the major constituent of the materials using statistical analysis. The precise tool used for development of these models was multiple regression analysis and the models were used to obtain the calculated (numerical) values of these properties for each of the materials under investigation.

Statistical tests were thereafter carried out to validate the models developed. The tests performed were pair t-tests, correlation coefficient and standard error; they were used to compare the experimental and numerical values of these properties which were found valid within the limit of experimental error. Computer software named "ROLLED STEEL INFORMATION SYSTEM 2010" was thereafter developed from the models which help to quickly estimate the relevant mechanical properties of the rolled ribbed medium carbon steels.

TABLE OF CONTENTS

	Page
Title	i
Approval	ii
Title page	iii
Certification	iv
Acknowledgement	v
Dedication	vii
Abstract	viii
Table of Contents	ix
List of Tables	xiv
List of Figures	xvii
List of Plates	xx
List of Appendix	xxii
Nomenclatures	xxiii
CHAPTER ONE	1
1.0 Introduction	1
1.1 Background of the Research	3
1.2 Justification for the Research	5
1.3 Aim and Objectives of the Research	5
1.4 Scope of the Research	6
1.5 Expected Contributions to Knowledge	6
CHAPTER TWO	8

2.0 Steels	8
2.1 Classification of Steel	8
2.1.1 Plain Carbon Steels	9
2.1.2 Alloy Steels	9
2.2 Plain Carbon Steels	9
2.2.1 Classification of Plain Carbon Steel	10
2.2.2 Medium Carbon Steel	11
2.3 Applications of Medium Carbon Steel	11
2.4 Rolling and Reinforcement bar Production	12
2.5 Rolled Product Quality Control	15
2.6 Mechanical Properties of Rolled Medium Carbon Steel	15
2.6.1 Tensile Properties	16
2.6.1.1 Tensile Strength	16
2.6.1.2 Modulus of Elasticity	17
2.6.1.3 Yield Strength	18
2.6.2 Hardness	19
2.6.3 Impact Strength	20
2.7 Metallography	20
2.8 Modelling and Simulation	21
2.8.1 Modelling	21
2.8.2 Simulation	22
2.8.3 Mathematical Modelling	22
2.8.3.1 Problem Definition	23

2.8.3.2 Simplification of the System	23
2.8.3.3 Model Formulation	24
2.8.3.4 Model Solution	24
2.8.3.5 Model Validation	24
2.8.3.6 Report	25
2.9 Model Development/Formulation	25
2.9.1 Multiple Regression Analysis	25
2.9.2 Estimation of Parameters	27
2.9.3 Least Square Method	27
2.9.4 Computer Aided Solution	29
2.9.5 Assumptions	29
2.10 Model Validation	30
2.10.1 Pair t-tests	30
2.10.2 Correlation Analysis and Coefficient of Correlation	32
2.10.3 Standard Error of Prediction	33
2.11 Past Researches on Modelling of Mechanical Properties of Materials and Experimental Validation	34
CHAPTER THREE	38
3.0 Research Methodology	38
3.1 Materials	38
3.2 Equipment	38
3.3 Cut off and Machine Operations	39
3.4 Determination of Mechanical Properties of Rolled	

Medium Carbon Steel	40
3.4.1 Tensile Tests	40
3.4.2 Hardness Test	41
3.4.3 Impact Test	42
3.5 Metallography	42
3.5.1 Selection of Samples	43
3.5.2 Grinding	43
3.5.3 Polishing	43
3.5.4 Etching	44
3.5.5 Microscopic examination	44
CHAPTER FOUR	45
4.0 Model Development, Validation and Development of Computer Software for the Model	45
4.1 Model Development	45
4.1.1 Statistical Analysis	45
4.2 Validation of the Developed Models	49
4.2.1 Pair t-tests	49
4.2.2 Correlation Coefficient	50
4.2.3 Standard Error of Prediction	50
4.2.4 Interpretation of Data	51
4.3 Development of Computer Software for the Models	57
4.3.1 Development of Algorithm and Flowchart	57
4.3.2 Computer Software Development	59

4.3.3 Computer Requirements	65
CHAPTER FIVE	66
5.0 Results and Discussions	66
5.1 Results	66
5.2 Discussions	77
5.2.1 Effect of Dependent Variables on the Mechanical Properties	77
5.2.1.1 Effect of Sample Sizes on Mechanical Properties	77
5.2.1.2 Effect of Chemical Composition on Mechanical Properties	81
5.2.3 Models with and without Iron	86
5.2.4 Validation of the Results	86
5.2.5 Limitation of the Models	87
CHAPTER SIX	89
6.0 Conclusions and Recommendations	89
6.1 Conclusions	89
6.2 Recommendations	90
6.3 Suggestions for further work	90
References	91
Appendix I	96
Appendix II	100
Appendix III	101
Results	113

LIST OF TABLES

	Page
Table 3.1: Chemical Compositions of the Rolled Ribbed Medium Carbon Steels used in the Research and Predictors (Independent Variables)	40
Table 4.1: Rule of Thumb for Interpreting the Correlation Coefficient R	52
Table 4.2: Pair t-test Analysis to Determine the Acceptable Confidence Interval Range of Transverse Rockwell Hardness Value A of Rolled Ribbed Medium Carbon Steel	53
Table 4.3: Pair t-test Analysis to Determine the Acceptable Confidence Interval Range of Longitudinal Rockwell Hardness Value A of Rolled Ribbed Medium Carbon Steel	53
Table 4.4: Pair t-test Analysis to Determine the Acceptable Confidence Interval Range of Tensile Strength at Maximum Load of Rolled Ribbed Medium Carbon Steel	54
Table 4.5: Pair t-test Analysis to Determine the Acceptable Confidence Interval Range of Tensile Strength at Break of Rolled Ribbed Medium Carbon Steel	54
Table 4.6: Pair t-test Analysis to Determine the Acceptable Confidence Interval Range of Yield Strength of Rolled Ribbed Medium Carbon Steel	55
Table 4.7: Pair t-test Analysis to Determine the Acceptable Confidence Interval Range of Impact Strength of Rolled Ribbed Medium Carbon Steel	55
Table 4.8: Correlation Coefficient and Standard Error Analysis of Transverse Rockwell Hardness Value A of Rolled Ribbed Medium Carbon Steel	56
Table 4.9: Correlation Coefficient and Standard Error Analysis of Longitudinal	

Rockwell Hardness Value A of Rolled Ribbed Medium Carbon Steel	56
Table 4.10: Correlation Coefficient and Standard Error Analysis of Tensile Strength at Maximum Load of Rolled Ribbed Medium Carbon Steel	56
Table 4.11: Correlation Coefficient and Standard Error Analysis of Tensile Strength at Break of Rolled Ribbed Medium Carbon Steel	56
Table 4.12: Correlation Coefficient and Standard Error Analysis of Yield Strength of Rolled Ribbed Medium Carbon Steel	57
Table 4.13: Correlation Coefficient and Standard Error Analysis of Impact Strength of Rolled Ribbed Medium Carbon Steel	57
Table 5.1: Transverse Rockwell Hardness Value A with Iron (Experimental Data, Numerical Data and Computer Software Results) of Rolled Ribbed Medium Carbon Steel	66
Table 5.2: Longitudinal Rockwell Hardness Value A with Iron (Experimental Data, Numerical Data and Computer Software Results) of Rolled Ribbed Medium Carbon Steel	67
Table 5.3: Tensile Strength at Maximum Load with Iron (Experimental Data, Numerical Data and Computer Software Results) of Rolled Ribbed Medium Carbon Steel	67
Table 5.4: Tensile Strength at Break with Iron (Experimental Data, Numerical Data and Computer Software Results) of Rolled Ribbed Medium Carbon Steel	68
Table 5.5: Yield Strength with Iron (Experimental Data, Numerical Data and Computer Software Results) of Rolled Ribbed Medium Carbon Steel	68

Table 5.6: Impact Strength with Iron (Experimental Data, Numerical Data and Computer Software Results) of Rolled Ribbed Medium Carbon Steel	69
Table 5.7: Transverse Rockwell Hardness Value A without Iron (Experimental Data, Numerical Data and Computer Software Results) of Rolled Ribbed Medium Carbon Steel	69
Table 5.8: Longitudinal Rockwell Hardness Value A without Iron (Experimental Data, Numerical Data and Computer Software Results) of Rolled Ribbed Medium Carbon Steel	70
Table 5.9: Tensile Strength at Maximum Load without Iron (Experimental Data, Numerical Data and Computer Software Results) of Rolled Ribbed Medium Carbon Steel	70
Table 5.10: Tensile Strength at Break without Iron (Experimental Data, Numerical Data and Computer Software Results) of Rolled Ribbed Medium Carbon Steel	71
Table 5.11: Yield Strength without Iron (Experimental Data, Numerical Data and Computer Software Results) of Rolled Ribbed Medium Carbon Steel	71
Table 5.12: Impact Strength without Iron (Experimental Data, Numerical Data and Computer Software Results) of Rolled Ribbed Medium Carbon Steel	72

LIST OF FIGURES

	Page
Figure 2.1: Iron – Iron-carbide Equilibrium Diagram	10
Figure 2.2: Description of the layout and various stages of production in a typical Inland Rolling Mill	14
Figure 2.3: A typical Engineering stress – strain curve	17
Figure 2.4: The processes involved in Mathematical Modelling.	23
Figure 2.5: General Procedure followed in using Computer Package.	29
Figure 3.1 : Standard Tensile Test Piece	41
Figure 3.2 : Hardness Test Piece	41
Figure 3.3 : V-notch Impact Test Piece	42
Figure 4.1: Flowchart of Software for the Models Developed	58
Figure 4.2: Title Phase of the Developed Software	60
Figure 4.3: Material Identification Result Phase of the Developed Software	61
Figure 4.4: Material Identification Phase of the Developed Software	61
Figure 4.5: Property Determination Selection Phase of the Developed Software	62
Figure 4.6: Data Entry Phase of the Developed Software	63
Figure 4.7: Model-Type Selection Phase of the Developed Software	63
Figure 4.8: Report Menu Phase of the Developed Software	64
Figure 5.1: The Variation of Transverse Rockwell Hardness Values A with Samples Sizes of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.	78

Figure 5.2: The Variation of Longitudinal Rockwell Hardness Values A with Samples Sizes of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.	79
Figure 5.3: The Variation of Tensile Strength at maximum load (N/mm^2) with Samples Sizes of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.	79
Figure 5.4: The Variation of Tensile Strength at Break (N/mm^2) with Samples Sizes of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.	80
Figure 5.5: The Variation of Yield Strength (N/mm^2) with Samples Sizes of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.	80
Figure 5.6: The Variation of Impact Toughness (KJ) with Samples Sizes of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.	81
Figure 5.7: The Variation of Transverse Rockwell Hardness Values A with %Carbon Content of Samples of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.	83
Figure 5.8: The Variation of Longitudinal Rockwell Hardness Values A with %Carbon Content of Samples of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.	84

- Figure 5.9: The Variation of Tensile Strength at maximum load (N/mm^2) with %Carbon Content of Samples of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values. 84
- Figure 5.10: The Variation of Tensile Strength at Break (N/mm^2) with %Carbon Content of Samples of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values. 85
- Figure 5.11: The Variation of Yield Strength (N/mm^2) with %Carbon Content of Samples of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values. 85
- Figure 5.12: The Variation of Impact Toughness (KJ) with %Carbon Content of Samples of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values. 86



LIST OF PLATES

	Page
Plate 1: Microstructure of 25mm Diameter of Rolled Ribbed Medium Carbon Steel. (X400) (Un-etched)	72
Plate 2: Microstructure of 25mm Diameter of Rolled Ribbed Medium Carbon Steel. (X400) (Etched)	73
Plate 3: Microstructure of 25mm Diameter of Rolled Ribbed Medium Carbon Steel. (X800) (Etched)	73
Plate 4: Microstructure of 20mm Diameter of Rolled Ribbed Medium Carbon Steel. (X400) (Un-etched)	73
Plate 5: Microstructure of 20mm Diameter of Rolled Ribbed Medium Carbon Steel. (X400) (Etched)	74
Plate 6: Microstructure of 20mm Diameter of Rolled Ribbed Medium Carbon Steel. (X800) (Etched)	74
Plate 7: Microstructure of 16mm Diameter of Rolled Ribbed Medium Carbon Steel. (X400) (Un-etched)	74
Plate 8: Microstructure of 16mm Diameter of Rolled Ribbed Medium Carbon Steel. (X400) (Etched)	75
Plate 9: Microstructure of 16mm Diameter of Rolled Ribbed Medium Carbon Steel. (X800) (Etched)	75
Plate 10: Microstructure of 12mm Diameter of Rolled Ribbed Medium Carbon Steel. (X400) (Un-etched)	75

Plate 11: Microstructure of 12mm Diameter of Rolled Ribbed Medium Carbon Steel. (X400) (Etched)	76
Plate 12: Microstructure of 12mm Diameter of Rolled Ribbed Medium Carbon Steel. (X800) (Etched)	76

LIST OF APPENDIX

Page

Appendix I: Statistical Tests used for the Validation of the developed models that estimate the Mechanical Properties of the Rolled Ribbed Medium Carbon Steels	96
Appendix II: Software Named "Rolled Steel Information System 2010"	100
Appendix III: Computer Algorithm for the developed "Rolled Steel Information System 2010"	101



NOMENCLATURES

X_1 = Diameter (Rod Size)

X_2 = Percentage Carbon

X_3 = Percentage Manganese

X_4 = Percentage Silicon

X_5 = Percentage Phosphorous

X_6 = Percentage Sulphur

X_7 = Percentage Chromium

X_8 = Percentage Nickel

X_9 = Percentage Copper

X_{10} = Percentage Cobalt

X_{11} = Percentage Tungsten

X_{12} = Percentage Iron

d = Pair difference between the Experimental and Numerical Data on each Column.

$\bar{d}$ = Mean Pair difference

$\text{Var}(d)$ = Variance of Pair difference

$\text{Var}(\bar{d})$ = Variance of Mean difference

t_v = Theoretical Number of Degrees of Freedom available for the Estimation of the Variance, i.e. $(n-1)$

N = Number of Paired test Samples

α = Confidence Interval (%)

S_d = Standard Deviation

$\text{Cov}(x,y)$ = Covariance of X and Y

$\hat{\sigma}_x$ = Variance of X

$\hat{\sigma}_y$ = Variance of Y

P_{xy} = Correlation Coefficient

$\bar{x}$ = Mean of X

$\bar{y}$ = Mean of Y

X = Experimental Value

Y = Numerical Value

Y_c = Predicted Value

Y_a = Experimental Value

Y = Actual Value (Experimental Value)

Y_r = Predicted value (Numerical Value)

THV_1 = Transverse Rockwell Hardness A of Model with Iron Inclusive

LHV_1 = Longitudinal Rockwell Hardness A of Model with Iron Inclusive

TSL_{Max1} = Tensile Strength at Maximum Load of Model with Iron Inclusive

$TS_{@Break1}$ = Tensile Strength at Break of Model with Iron Inclusive

YS_1 = Yield Strength of Model with Iron Inclusive

IS_1 = Impact Strength of Model with Iron Inclusive

THV_2 = Transverse Rockwell Hardness A of Model without Iron

LHV_2 = Longitudinal Rockwell Hardness A of Model without Iron

TSL_{Max2} = Tensile Strength at Maximum Load of Model without Iron

$TS_{@Break2}$ = Tensile Strength at Break of Model without Iron

YS_2 = Yield Strength of Model without Iron

IS_2 = Impact Strength of Model without Iron



CHAPTER ONE

1.0 INTRODUCTION

As knowledge increases in less and less time, and as new methods of manufacturing become more complex, materials take an increasingly important role. Demands for safer materials have made Engineers to become knowledgeable in the field of materials. Consequently, these persons must understand the chemical, physical and mechanical properties of materials. Engineers must be able to plan, produce and predict the required strength of their products as these products function in everyday life and in extreme environments. They must be aware of microstructures of materials and their relationship to mechanical properties (Vernon, 1977).

An understanding of the properties of materials is essential in both the design and applications in any engineering project if it is to prove satisfactory for its intended purpose (Neil, and Ravindra, 1996). The ability of a material to adequately perform in service demonstrates several mechanical properties of the material. For instance, the network of bridges and structures, high rise buildings and road ways are illustrations of the capabilities of materials (Vernon, 1977).

Materials Engineers are concerned with producing and fabricating materials to meet service requirements as predicted by the laboratory analyses, especially in their mechanical properties. Hence, materials are frequently chosen for structural application provided they have the desirable combinations of mechanical properties (Williams, 2000). These mechanical properties of materials are of prime interest to the Engineers and the results of tests to determine these properties are used for various purposes

(Pascoe, 1978). "Mechanical property is defined as the behaviours and characteristics of a material that are displayed when a force is applied to it" (Kenneth, 1979). They are of concern to a variety of parties such as producers and consumers of materials, research organisations, government agencies, that have differing interests. Consequently, it is imperative that there be some consistency in the manner in which tests are conducted, and in the interpretation of results. This consistency is accomplished by using standardized experimental testing techniques and/or theoretical and mathematical (modelling) techniques (Williams, 2000).

Thus, it is essential to measure the relevant mechanical properties of materials. Its determination also provides design data for Engineers as well as a check on the standard of raw materials and heat treatment methods being used. The mechanical properties that are most important to Engineers are:

(i) **Strength:** Ability of a material to withstand application of load without fracture/failure; (ii) **Hardness:** Ability of a material to resist abrasion, deformation and indentation; (iii) **Toughness:** Ability of a material to resist fracture usually after the elastic limit has been exceeded; and (iv) **Fatigue:** Ability of a material to withstand repeated, cyclic, or fluctuating loading without failure.

Advances in computer technology have made design engineering quite sophisticated. Mathematical models are used to study stresses and process kinetics as well as determination of materials properties (Kenneth, 1979). For computer modelling of various kinds, hot steel rolling technologies, the prediction of mechanical properties of final products is a question of great importance (Simecek and Hajduk, 2007). It is therefore the purpose of this research work to present information on the development of

computer software for the determination of mechanical properties of a very universal engineering material – rolled medium carbon steel, commonly used in various engineering designs. Large amounts of carbon steel are used for the reinforcement of concrete in buildings, bridges and marine structures. The reinforcement bars therefore constitute a competitor to structural steel plates and sections (Llewellyn, 1992). During the 1980s in UK, there was a dramatic increase in the structural steel work in multi-storey buildings primarily at the expense of in situ concrete (Llewellyn, 1992).

Materials selection is based upon properties. The design engineer must decide the properties required of a material for the designed component and then weigh the properties which are measured in the laboratories of candidate materials (Kenneth, 1979).

1.1 BACKGROUND OF THE RESEARCH

Steel is a material composed primarily of iron and carbon with traces of other elements. It is an alloy of iron and carbon. It is plain carbon steel when carbon is the predominant alloy element and referred to as alloy steel when any other alloying element or its combination play key role in modifying the properties of the steel. It is the most versatile of all engineering materials. This is due to its several properties such as high strength, formability and ready availability at reasonably low cost compared to other materials having similar properties. Plain carbon steels, particularly medium carbon steel is widely used for civil/structural works in the form of reinforcement or plain bars of different sizes.

The ability of the steel bars to function as expected in these areas of application is dictated by the mechanical properties. Therefore, the production of the steel bars to meet

service requirements and estimation of the mechanical properties are very imperative. Hence, it becomes necessary for all manufacturers (Rolling mills operators) of steel products (plain and ribbed reinforced bars) to give adequate and correct data about the mechanical properties of their products. This will assist government regulatory agencies such as Standard Organisation of Nigeria (SON) and research institutes in their primary responsibilities as well as the design Engineers of buildings/structures to know the limits of application of these products.

However, the manufacturers have declined from proper estimation of these properties due to some constraints. These include:

- (i) National energy problem which has forcefully increased the cost of production beyond acceptable level;
- (ii) The cost of procurement by importation of the necessary equipment and facilities in order to establish a standard quality control laboratory;
- (iii) The cost of labour and manpower required for the exercise;
- (iv) Time factors;
- (v) Cumbersomeness in carrying out the tests experimentally;
- (vi) Problem of scattering of data which make it difficult to obtain an exact quantities no matter the level of precision of the measuring apparatus (Williams, 2000); and
- (vii) The risk of accident in experimental techniques among others.

Therefore, this research work has been carried out to assist in finding a very simple and flexible approach to investigate the mechanical properties theoretically with the aid of computer software program.

1.2 JUSTIFICATION FOR THE RESEARCH

Due to recent advancement in science and technology coupled with the complexity in manufacturing system as well as automation of production systems in the industries, it therefore becomes vital that the mechanical properties of products be investigated and determined accurately. The data obtained should then be made available to the user of the products. However, due to non-availability of equipment and necessary facilities to experimentally carry out the tests, most industries in the country do no longer consider the quality assurance of their product a must-determine before marketing. The users at their own end too have the problem in the determination of these properties. In developing country like Nigeria, problems of determination of the mechanical properties of rolled ribbed bars are being experienced by the indigenous rolling mills. This may have contributed immensely to the incessant collapse of building being experienced in developing countries like Nigeria.

There is therefore a need for models that will predict the mechanical properties in order to improve the reliability of the test results and overall efficiency of the production system. There is need to devise a simple, flexible and efficient means of estimating these properties at a relatively low cost. This is the rationale behind the development of models for predicting the mechanical properties and software to estimate the modelled mechanical properties of the rolled ribbed medium carbon steel.

1.3 AIM AND OBJECTIVES OF THE RESEARCH

The aim of this research is to develop a quantitative approach to determine and estimate the mechanical properties (Tensile Strength at maximum load, Tensile Strength at break,

Yield Strength, Hardness values and Impact Toughness) of rolled ribbed bars of medium carbon steel. The objectives of the research are to:

- (i) determine the mechanical properties (Transverse and Longitudinal hardness values, Impact Toughness, Tensile Strength at maximum load, Tensile Strength at break and Yield Strength) of rolled ribbed medium carbon steel experimentally;
- (ii) develop models, using the data obtained in (i) and validate the developed models;
- (iii) develop computer program for the models developed in (ii) and validate the developed computer software.

1.4 SCOPE OF THE RESEARCH

The scope of the research covered the samples of rolled ribbed medium carbon steel of diameters 12mm, 16mm, 20mm, and 25mm produced by Ajaokuta Steel Company Rolling Mill, Ajaokuta, Kogi State and Delta Steel Company Rolling Mill, Aladja, Delta State. These samples were chosen because they are most widely used for building and civil construction works. The modelling and software development were limited to the scope.

1.5 EXPECTED CONTRIBUTIONS TO KNOWLEDGE

On successful completion of the research, it is expected that it will bring about an improvement in the efficiency of production system. The problem of procuring expensive quality control facilities will be minimized. It will also ensure flexibility of the process at a reasonably low cost without undermining the desired quality of products. Dependency on foreign importation of equipment will be reduced thereby enhancing the foreign

exchange power of the nation. It will assist the producers of reinforced bar to estimate the mechanical properties of their products at easily. The users of the products can also confirm the estimated properties easily before use. The government agency like Standard Organisation of Nigeria (SON) can make use of the software developed in ensuring compliance of products to specifications. In addition, it will be of advantage to the research institutes as well.

CHAPTER TWO



2.0 STEELS

Steels are iron-carbon alloys that may contain appreciable concentrations of other alloying elements; there are thousands of alloys of steel that have different compositions and/or heat treatments. The mechanical properties are sensitive to the content of carbon, which is normally less than 1.0 wt % (Williams, 2000). When iron-carbon alloys have less than 0.005% carbon present at room temperature, they are considered to be pure iron. Pure iron is soft, ductile, and relatively weak. It is not normally used as an engineering material because of its low strength, but it is used for special applications such as magnetic devices.

From the commercial standpoint, steels have a low carbon limit of approximately 0.06% carbon. On the other end of the carbon content scale, iron-carbon alloys with more than approximately 2.03% by weight of carbon are considered to be cast irons. Thus, steels are alloys of iron and carbon with carbon limits between approximately 0.06% and 2.03% (Kenneth, 1979).

2.1 CLASSIFICATION OF STEEL

In general, steels may be classified into two broad groups namely:

- Plain carbon steels
- Alloy steels

2.1.1 Plain Carbon Steels

These are the steels in which carbon is the main alloying element that governs the properties of the steel with only residual concentrations of impurities (other elements) and a little manganese.

2.1.2 Alloy Steels

These are steels in which one or more alloying elements are intentionally added in specific concentrations to impart some peculiar characteristics. In such steels, carbon and alloying elements contribute towards the properties of the steels. These include tool and stainless steels.

2.2 PLAIN CARBON STEELS

Plain carbon steels are simply alloys of iron and carbon with carbon as the major strengthening agent. The American Iron and Steel Institute (AISI) more rigorously describe carbon steels as steels with up to 2% carbon and only residual amount of other elements, that is, kept below certain limited quantities that cannot influence the properties of the steels except those added for de-oxidation (e. g. Al) and with silicon, copper and manganese limited to 0.6%, 0.6% and 1.65% respectively. These steels make the largest fraction of steel production. They are available in almost all production forms: sheets, strips, bars, plates, tubes, pipes, and wires. They are used for high-production items such as automobiles and appliances; and also play a major role in machine design for base plates, housings, chutes, structural members and literally hundreds of different parts (Kenneth, 1979).

2.2.1 Classification of Plain Carbon Steel

Plain carbon steel can further be subdivided on the basis of various factors. It can be further classified on the basis of carbon content, structures at room temperature at slow cooling, quality and applications. For instance, it may be recalled that steel having 0.8% carbon is called eutectoid steel which has completely pearlitic structure on slow cooling. Hypo-eutectoid steel contains pro-eutectoid ferrite and pearlitic structure while Hyper-eutectoid contains pro-eutectoid cementite and pearlite. This is illustrated in the iron-carbon equilibrium diagram shown in Figure 2.1.

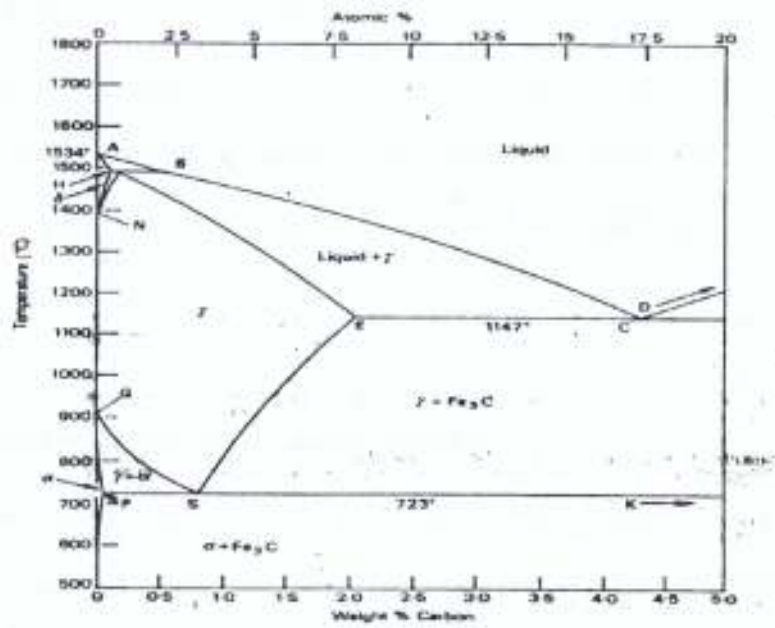


Figure 2.1: Iron – Iron-carbide Equilibrium Diagram (Honeycombe and Bhadeshia, 1995)

However, for all practical purposes, they are best classified on the basis of carbon content into:

Dead mild steel	0.05-0.1 %C
Mild steel or Low carbon steel	0.1-0.25 %C
Medium carbon steel	0.3 – 0.6 %C
High carbon steel	0.6 – 1.2 %C

These constitute over 90% of the total world steel production and mild steels take the major share of these (Rajan, et. al. 1988).

2.2.2 Medium Carbon Steel

These are carbon steels that have carbon concentrations between 0.3% and 0.6% weight of carbon. It is a class of steel that has combination of properties higher than that of low carbon steels, though at the expense of ductility. It is averagely responsive to heat treatment. Hence, it can be heat treated by austenitizing, quenching and then tempered to improve their mechanical properties. It has good strength and fabricability. It also has good toughness and shock resistance.

2.3 APPLICATIONS OF MEDIUM CARBON STEEL

The areas of application include railway wheels and tracks, gears, crankshafts and other machine parts; and structural components. In fact, they are most widely used steels for civil construction works and equipment manufacturing. These include bridges, road culverts, buildings and they are very reliable. They are usually products of hot rolled steel sections in normalized state which make them have higher strength, and lower ductility and good toughness than the low carbon grade (William, 2000 and Lakhtin, 1979).

2.4 ROLLING AND REINFORCEMENT BAR PRODUCTION

This is the method of shaping metals by subjecting the work piece to load from oppositely rotating rolls. It is a direct compression – type of pressure shaping of metal.

It is refer to as hot rolling when the process is carried out at elevated temperature of at least greater than the $0.4T_m$ (melting temperature for steel). The work piece (billet) is first heated in a reheating furnace before it is discharged onto the rolling line. In hot rolling, two counter processes run almost simultaneously and are:

- I. – Work hardening caused by deformation process and
- II. – Recrystallization, that is, eliminating the work hardening on cooling.

(Javoronko

and Chaturvedi, 1981).

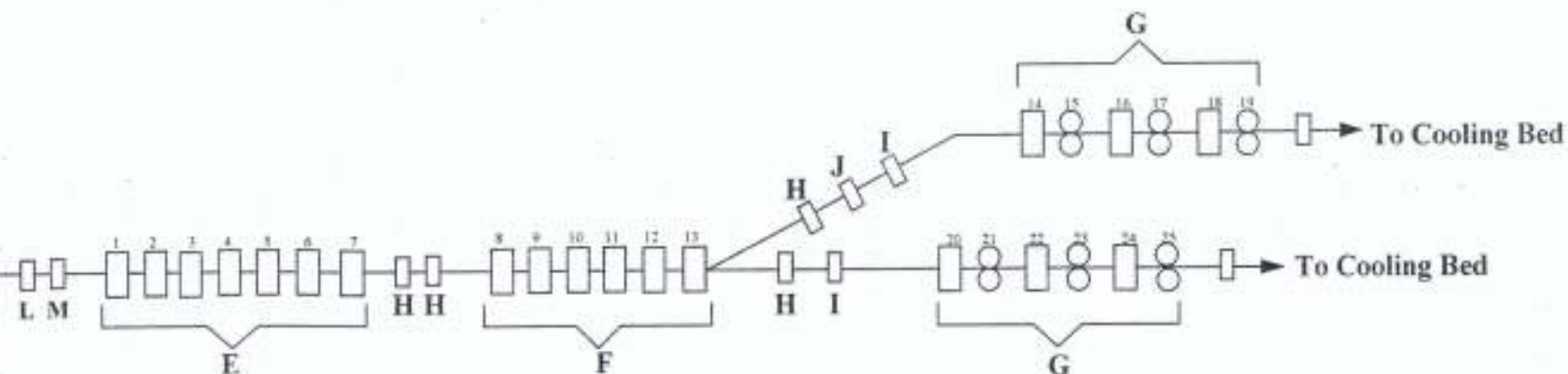
The process of rolling is characterized not by the temperature at which the deformation takes place but by the presence of the recrystallization process. The deformation process is followed immediately by the recrystallization process.

Hot rolling is the major rolling operation where several products of various sizes and shapes are produced, particularly, all structural steel sections. Merchant sections comprise squares and rounds from 5mm to 120mm among others. And these include special sections used in various specific applications like window sections, plates and reinforcement bars. In fact, recently, merchant mills have been used for products of cross-sections varying both in shape and size along their length. Such products are extremely useful these days due to increasing challenges in building constructions as demanded by urban building requirements such as high rise building and aseismic

structural design for greater safety from collapse in severe earthquakes. This accounts for the development of low yield ratio and narrow yield point range steels for such applications (Javoronko and Chaturvedi, 1981).

The production processes of reinforcement bars in rolling mills comprise of three major operations/sections and are: heating section, rolling (proper) section and the finishing unit. The Figure 2.2 describes the layout showing the various stages of production in a typical inland rolling mill.

AJAKUTA STEEL COMPANY LIMITED
OPERATIONS DEPARTMENT, ROLLING MILLS DIVISION
LIGHT SECTION AND BAR MILL



NOTATIONS

- | | | | |
|----|---|----|-----------------------------------|
| A: | RECEIVING ROLL TABLE | B: | WALKING BEAM OF REHEATING FURNACE |
| C: | FURNACE CHARGING EQUIPMENT | D: | FURNACE EJECTOR RAM |
| E: | ROUGHING GROUP OF STANDS (SEVEN TWO HIGH NON REVERSIBLE CONTINUOUS HORIZONTAL STANDS) | | |
| F: | INTERMEDIATE GROUP OF STANDS (SIX TWO HIGH NON REVERSIBLE HORIZONTAL STANDS) | | |
| G: | FINISHING GROUP – TWO MILLS (EACH HAVING SIX STANDS, ONE VERTICAL STAND & ONE HORIZONTAL STAND ALTERNATELY) | | |
| H: | FLYING SHEAR | I: | EMERGENCY SHEAR |
| J: | FEED ROLL | K: | CRANK-CAM SHEAR |
| L: | PINCH ROLL | M: | DISTRIBUTING DRUM |

Figure 2.2: Description of the Layout and Various Stages of Production in a Typical Inland Rolling Mill

2.5 ROLLED PRODUCT QUALITY CONTROL

The quality of rolled products is determined primarily by that of the steel melting and casting stage of the production. With modern mass production, the pre-requisites for obtaining high quality are steady conditions of processing and well organized control at all stages of the metallurgical cycles.

After the first two cycles, that is, iron and steel making cycles have been confirmed satisfactory, then the third and the last stage of the metallurgical cycle is rolling. The conformity of the rolled products to the order specifications is determined on the basis of the procedure control information and on that of the data subsequent to the control over dimensions and surface condition of the products, carried out in the course of production, as well as on the ground of the final data on finishing, sorting, packing and marking; and very fundamentally, on that of findings obtained as a result of the final mechanical tests. It is these mechanical tests that determine the applicability of the products and guarantee their reliability in service. This is carried out in the course of production, the samples being cooled under similar conditions to those prevalent in the production (Burtsev and Perlov, 1973).

2.6 MECHANICAL PROPERTIES OF ROLLED MEDIUM CARBON STEEL

Mechanical properties are of foremost importance in selecting medium carbon steels as materials for structural applications. There are many tests to measure these mechanical properties, but about three of them are most commonly estimated because they supply the most useful information. They are:

- (i) Tensile tests

(ii) Hardness measurement and

(iii) Impact Strength (Kenneth, 1979).

2.6.1 TENSILE PROPERTIES

These include tensile strength, yield strength, ductility, modulus of elasticity; percentage elongation at fracture and percentage reduction in area.

2.6.1.1 Tensile Strength

The Tensile Strength (TS) is the stress at the maximum loading on the engineering stress - strain curve. This corresponds to the maximum stress that can be sustained by a structure in tension if this is applied and maintained and beyond which fracture will occur. All deformation up to this point is uniform throughout the gauge region of the tensile specimen. Tensile strength or ultimate tensile strength (UTS) is the maximum load divided by the original cross-sectional area of the specimen.

The tensile strength is the value most often quoted from the results of a tension test, yet in reality, it is a value of little fundamental significance with regard to the strength of a metal. For many years, it was customary to base the strength of the members on the tensile strength, suitably reduced by a factor of safety. The current trend is to use the more rational approach of basing the static design of ductile metals on the yield strength. However, because of the long practice of using the tensile strength to determine the strength of materials, it has become a very familiar property, and as such it is a very useful identification of a material in the same sense as the chemical composition serves to identify a metal or alloy. Further, because the tensile strength is easy to determine and is

a reasonably reproducible property, it is useful for the purposes of specifications and quality control of product. Extensive empirical correlations between tensile strength and properties such as hardness and fatigue strength are often quite useful (George, 1988).

The test is carried out by using machines which apply a tensile load by attaching one end of the test sample to a movable member. The crosshead is then driven in such a manner so as to pull the sample apart. Figure 2.3 shows a typical stress – strain curve obtained from a tensile test (Kenneth, 1979).

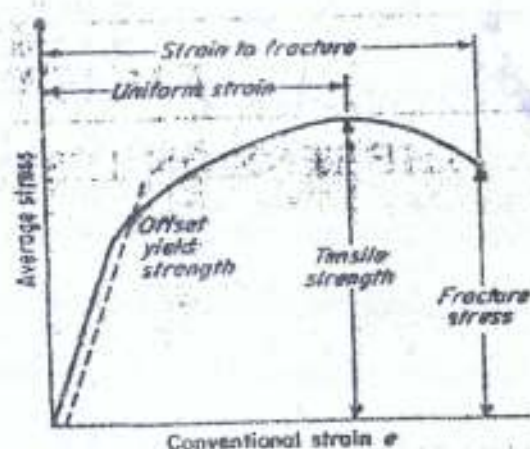


Figure 2.3: A typical Engineering stress – strain curve (Dieter, 1988)).

2.6.1.2 Modulus of Elasticity

This is the ratio of stress to strain in a material loaded below its yield strength; it is a measure of rigidity (Kenneth, 1979). It is the first part of the tensile test where the material is deformed elastically. That is, if the load on the specimen is released, the specimen will return to its original length. For metals such as medium carbon steels, the maximum elastic deformation is usually less than 0.5% (William, 1990). The slope of the

initial linear portion of the stress – strain curve is the modulus of elasticity or young's modulus. The greater the modulus, the smaller is the elastic strain resulting from the application of a given stress. This property is needed for computing deflections of beams and other members, it therefore makes it an important design value and it is one of the most structure-in-sensitives of the mechanical properties.

2.6.1.3 Yield Strength

This is a very important value for use in engineering structural design since it is the stress at which a metal or alloy show significant plastic deformation. Because there is no definite point on the stress – strain curve where elastic strain ends and plastic strain begins, the yield strength is usually chosen to be that strength when a definite amount of plastic strain has occurred. For American engineering structural design, the yield strength is chosen when 0.2% plastic strain has taken place as indicated on the engineering stress – strain curve of Figure 2.3. Whereas in United Kingdom, 0.1% off set yield strength is commonly used.

The 0.2% yield strength is determined from engineering stress – strain diagram by drawing a parallel line to the elastic (linear part of the curve at 0.002% in/in (m/m) strain as indicated in Figure 2.3, the point where this line intersects the upper parts of the stress – strain horizontal line is drawn to the stress axis. The stress at the point where the horizontal line intersects the stress axis is the 0.2% off set yield strength (William, 1990). It is sometimes refer to as proof stress which is used for design and specification purpose because it avoids the practical difficulties of measuring the elastic limit or proportional limit (Llewellyn, 1992).

2.6.2 Hardness

The mechanical property is a measure of the resistance of material to permanent deformation i.e. localized plastic deformation (William, 1990 and William, 2000).

In the early hardness tests, it was based on natural minerals using a scale constructed based on the ability of one material to scratch another that was softer. Mohs scale was devised to determine the qualitative and somewhat arbitrary hardness indexing scheme. The scale ranged from 1 on the soft end for talc to 10 for diamond.

Quantitative hardness techniques have been developed over the years in which a small indenter is forced into the surface of the material to be tested under controlled conditions of load and rate of application. The depth or size of the resulting indentation is measured, which in turn is related to a hardness number; the softer the material, the larger and deeper the indentation, and the lower the hardness index number. However, measured hardness is only relative rather than absolute. Therefore, care should be exercised when comparing values determined by different techniques (William, 2000).

Hardness tests are commonly performed more frequently than any other mechanical tests. The reasons for this include:

- (i) They are simple and inexpensive – the specimen requires no special preparation and the testing apparatus is simple and not expensive.
- (ii) It is a non-destructive test – the specimen is neither fractured nor excessively deformed; the deformation is only a small indentation.
- (iii) Other mechanical properties such as tensile strength may be estimated from hardness data.

The hardness testers usually used are Knoop, Rockwell, Brinell and Vickers micro hardness testers. The hardness number for each of these tests depends on the shape of the indentation and the applied load. However, a digital hardness tester now available which incorporates both Rockwell and Brinell methods and a readout display.

2.6.3 Impact Strength

This is the ability of a material to absorb energy in the plastic range. In most engineering design application such as bridges, overhead ways and high rise buildings, ability to withstand occasional stresses above the yield stress without fracture is particularly desirable in structural steels. It is otherwise referred to as toughness and defined as ability to resist shock (George, 1988).

Toughness is a commonly used concept that is difficult to pin down and define. A way of estimating the toughness is to consider that it is the total area under the stress-strain curve. The area is an indication of the amount of work per unit volume which can be done on the material without causing it to rupture. For instance, a high carbon (spring) steel will have a higher yield and tensile strength than the medium-carbon (structural) steel. But the structural steel is more ductile and has a greater total elongation. That is, the total area under the stress-strain curve will be greater for structural steel; therefore it is a tougher material with better shock resistance (Daniel, 1985).

2.7 METALLOGRAPHY

This is basically the study of structures and constitution of metals and alloys, using metallurgical microscopes and magnifications from 100x to 1500x, so that the physical

and mechanical properties of an alloy can be related to its observed microstructures. The metallographic examination can therefore, be used in quality control and to predict and/or explain the mechanical properties of an alloy to aid in determining the cause of failure of a metallic component (Sherif, 1994).

The procedures for the study involve the following:

- (i) Cutting
- (ii) Mounting
- (iii) Grinding
- (iv) Polishing
- (v) Etching
- (vi) Micro-examination (microscopy) and
- (vii) Photo-microscopy (micrograph)

A specimen will be cut off the sample, ground on various grades of emery paper and polished to a mirror finish on cloth with diamond paste. This will be followed by etching with 2% Nital, dried and examination on M400X and M800X microscope fitted with a digital camera and focused image (Oyetunji, 2007).

2.8 MODELLING AND SIMULATION

2.8.1 Modelling

This is a simplified representation of a system or part of a system in a physical mathematical form (Dilwyn and Mike, 1993) that is suitable for demonstrating the behaviour of the system. It is an act of making a simple description of a system or process that can be used to illustrate or explain the system.

2.8.2 Simulation

This is the process of subjecting model to various input or environmental conditions in order to observe the behaviour and subsequently explore the nature of the results obtained from the real world system. It involves the manipulation of the model to create a real life using computer models to study the behaviour that could exist in reality.

2.8.3 Mathematical Modelling

This consists of applying mathematical skills to obtain useful answers to real life problems (Dilwyn and Mike, 1993), that is, the activity of translating real life problem into mathematics for subsequent analysis. A mathematical model will be created and its solution will usually provide information useful in dealing with the original problem. The components of the system are represented by idealized element that have essential characteristics of the real component and whose behaviour can be described by mathematical equation called model and they are very useful in making predictions when solved and interpreted. The activity of modelling is a process which involves a number of clearly identifiable stages. The most helpful way of representing these stages is by means of a flowchart.(Dilwyn and Mike, 1993) and this is as shown in Figure 2.4.

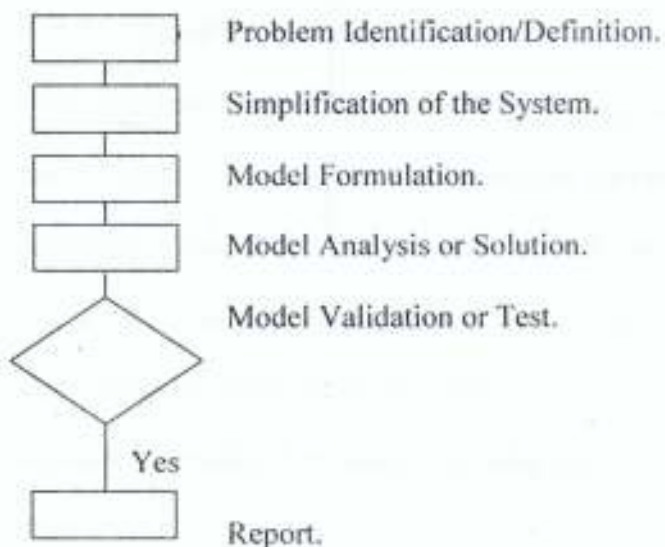


Figure 2.4: The processes involved in mathematical modelling. (Cross & Moscardini, 1984 and Dilwyn & Mike, 1993)

2.8.3.1 Problem Definition

The first stage is aimed at identifying the real problems to be addressed and outcome of the modelling. This can be accomplished by providing answers to the following questions among others: What do we want to know? What is the purpose and objective of the modelling? What are the sources of facts and data and are they reliable? Is there any particular unique answer to be found? (Dilwyn and Mike, 1993).

2.8.3.2 Simplification of the System

This stage involves collection of relevant data and examining them for information explaining the behaviour of variables. The list of relevant factors is identified and the most significant among them are noted for consideration.

2.8.3.3 Model Formulation

The significant variables are denoted by assigning units and state all assumptions made on the system. The goal to be achieved is quantified by translating it into mathematical equations using relevant mathematical tool such as statistics, numerical methods and operational research among others.. Each factor is given a sense of value by assigning a state which is usually low case alphabets. In the course of this project, multiple regression analysis as a tool will be used to develop the models.

2.8.3.4 Model Solution

The mathematical model of the problem formulated in the above stage is solved using algebraic and/or numerical methods, calculus, statistics and graphs. (Dilwyn and Mike, 1993) among other tools. The selection of a particular tool to be used depends on the nature of problem to be solved, parameters involved, factors to be considered and the aim to be achieved. Write computer program or use a prepared package if available and use a simulation package if necessary. Extract values for the variables that we want either in tabular or graphical form. (Dilwyn and Mike, 1993).

2.8.3.5 Model Validation

Once the model equations are formed and solved, the next stage of the model building is that of testing if the solution obtained is reasonable in serving the purpose which it was meant i.e. whether it conforms to reality. This is done by interpreting the obtained result followed by its validation. This is achieved by ensuring that the model solution answer the following questions. Does the prediction agree with real data?; Has the model fulfil its

purpose when it is evaluated?; Can the model be significantly improved by greater mathematical sophistication? and do the interim results suggest that more accuracy is needed by rerunning with an improved model? (Dilwyn and Mike, 1993). If the questions are satisfactory, go on to box 6 of Figure 2.4, but if otherwise, go back to the second box. This is important; very often the modelling cycle is traversed a number of times before the results are satisfactory. The Statistical methods of testing will be used to validate the model to be developed in this research work.

2.8.3.6 Report

The last stage is the writing of the report in such a way that the important features are clear and the result that is required stands out. Who is the report for and what do the readers want to know? Also, how much detail is required in the report are important.

2.9 MODEL DEVELOPMENT/FORMULATION

Multiple regression analysis technique has been used in this study for the models development.

2.9.1 Multiple Regression Analysis

Generally, regression analysis shows how it could be used to develop an equation (model) that would estimate the relationship between variables. In multiple regression, the objective is to build a probabilistic model that relates a dependent variable Y to more than one independent or predictor variables ($N > 2$) and denote these predictors by $X_1, X_2, \dots, X_N$; (Oyetunji, 2007 and Anderson, et. al 1981)

A general additive statistical multiple regression model, which relate independent variable Y to predictor variables $x_1, x_2, x_3, \dots, x_N$ is of the form

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n + \varepsilon \quad \dots\dots\dots (2.1)$$

Where

$\beta_0, \beta_1, \beta_2, \dots, \beta_n$ are unknown parameters,

ε is a random variable and

$x_1, x_2, x_3, \dots, x_N$ are known constants. (Azeez, et. al. 2004)

The random variation ε is assumed to be normally distributed with mean value 0 and variance δ^2 for many values of $x_1, x_2, x_3, \dots, x_N$. Thus, implies that for fixed $x_1, x_2, x_3, \dots, x_N$ values, Y has a normal distribution with variance δ^2 and (mean Y value for fixed $x_1, x_2, x_3, \dots, x_N$ values) and $\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n + \varepsilon$.

Since we assume that $E(\varepsilon) = 0$, therefore

$$E(Y) = \beta_0 + \beta_1 x_1 + \dots + \beta_2 x_2 + \dots + \beta_n x_n \quad \dots\dots\dots (2.2) \quad (\text{Azeez, et. al. 2004 and Mendenhall, et. al. 1981})$$

The physical interpretation of the linear model Y says that Y is equal to an expected value $\beta_0 + \beta_1 x_1 + \dots + \beta_2 x_2 + \dots + \beta_n x_n$ (a function of the independent variable $x_1, x_2, x_3, \dots, x_N$ plus a random error ε). From a practical point of view, ε acknowledge the inability to provide an exact model for nature. (Mendenhall, et. al. 1981).

Thus, just as $\beta_0 + \beta_1 x$ describe the mean value Y as a function of x in simple linear regression, the $E(Y)$ is often referred to as true or population regression function $E(Y)$ while the β 's are the population regression coefficients. The regression coefficient β_1 is interpreted as the expected change in Y associated with a 1-unit increase in x_1 while $x_2,$

$X_3, \dots, X_N$ are held constant. Analogous interpretations hold for $\beta_1, \dots, \beta_n$ (Oyetunji, 2007).

2.9.2 Estimation of Parameters

As in the case of simple linear regression $E(Y) = \beta_0 + \beta_1 x$, where $\beta_0 + \beta_1 x$ are estimated using a method of least square, it is possible to compute a set of coefficients of β_i s in the expression. (Wilfrid and Frank, 1969).

$$Y = \beta_0 + \beta_1 x_1 + \dots + \beta_2 x_2 + \dots + \beta_n x_n \quad \dots \dots \dots (2.3)$$

The coefficients are determined to provide the minimum sum of squares of differences between the observed $Y_{i \cdot s}$ and this linear combination of the X values.

2.9.3 Least Square Method

This is the best, most accurate and reliable method of solving a regression function (Azeez, et. al. 2004). It is an attempt to minimize the sum of squares of the distances between the observed values of the dependent variable Y and the estimated regression function.

Mathematically,

Least square objective

$$M_{in} \sum (Y_i - E(Y))^2 \quad (2.4)$$

Where

Y_i = observed value of dependent variable for i th observation

$E(Y_i)$ = Estimated value of the dependent variable based upon the estimated regression function.



$$E(Y) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n + \varepsilon \text{ (Anderson, et. al 1981)}$$

However, more generally, if we let the observations on the first individuals be denoted/represented by

$$Y_1, X_{11}, X_{21}, X_{31}, \dots, X_{N1}$$

Those on the second individual by

$$Y_2, X_{12}, X_{22}, X_{32}, \dots, X_{N2}$$

and so on to the Kth or last individual

$$Y_N, X_{K1}, X_{2k}, X_{3k}, \dots, X_{NK}$$

Then, the required solution $\beta_0, \beta_1, \dots, \beta_k$ is obtained by solving for these coefficients in the following set of equations

$$n\beta_0 + \beta_1 \sum x_{1j} + \beta_2 \sum x_{2j} + \dots + \beta_n \sum x_{nj} = \sum Y_j$$

$$\beta_0 \sum x_{ij} + \beta_1 EX_{ij} + \beta_2 EX_{ij}x_{2j} + \beta_n EX_{ij}x_{nj} = EX_{ij}Y_j$$

$$\dots\dots\dots$$

$$\dots\dots\dots$$

$$\dots\dots\dots$$

$$\beta_0 EX_{kj} + \beta_1 EX_{ij}X_{kj} + \beta_k EX_{k-j}X_{kj} + \beta_s EX^2(k) = EX_{kj}Y_j \quad \dots\dots\dots (2.5)$$

Solving those equations yield the least square estimates $\beta_0, \beta_1, \dots, \beta_k$. In general, the equation (2.5) can be solved manually by first computing all coefficients of β_i s and then using matrices particularly, Gaussian elimination method. (Oyetunji, 2007)

The computations, although not theoretically complex, are difficult even for N as small as 4 or 5. The arithmetic is not only tedious but it is hazardous since it is difficult to detect

error or to be sure that errors resulting from the use of a limited number of significant digits are not building up and destroy the accuracy of the results. (Wilfrid and Frank, 1969).

2.9.4 Computer Aided Solution

Generally, multiple regression analysis is solved using computer programs that can routinely generate the values of the least square estimates. In fact, several computer packages have been developed especially to handle a variety of statistical computations including multiple regression analysis. Three of the more common packages available are BMDP (Biomedical Computer Programs; P series), SAS (Statistical Analysis System) and SPSS (Statistical Package for the Social Sciences). (Anderson, et. al., 1981).

The general procedure that is followed in using such packages is shown in Figure 2.5. However, once data have been entered into the computer, the regression program takes over and computes the least square estimators together with a variety of other information that is printed out on a report of the user.

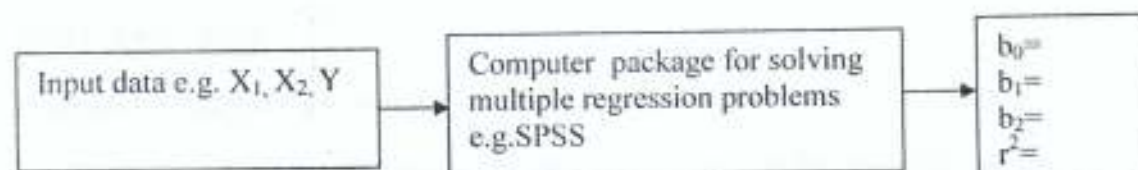


Figure 2.5: General procedure followed in using Computer package.

2.9.5 Assumptions

The following assumptions are made in order to justify the use of the models

$$1. \quad Y = E(Y) + E = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n + \varepsilon \quad \dots \dots \dots (2.6)$$

2. For any given set of values of $x_1, x_2, \dots, x_n$, ε has a normal distribution with mean equal to 0 and variance equal to δ^2 and is the same for each set of Y values
3. The random errors are independent (in a probabilistic sense)
4. The observed values Y are based on a random sample from the assumed normal probability distribution and that each observation is independent of all other observations.

2.10 MODEL VALIDATION

This stage of the modeling involve testing if the solution obtained is reasonable in serving the purpose it was meant to serve, i.e. whether it conforms to reality. Statistical tests will be used to validate the models to be developed. The experimental and numerical data of each property will be subjected to the following statistical tests:

- i. Paired t-test
- ii. Correlation Coefficient
- iii. Standard Error of Prediction

2.10.1 Pair t-tests

The pair t- test technique uses the following nomenclatures:

d = Pair difference between the experimental and numerical data on each column.

$\bar{d}$ = Mean Pair difference

$\text{Var}(d)$ = Variance of Pair difference

$\text{Var}(\bar{d})$ = Variance of mean difference

t_v = Theoretical number of degrees of freedom available for the estimation of the variance

i.e. (n-1)

N = Number of paired test samples

α = Confidence interval (%)

Sd = Standard deviation

The paired t-test will be evaluated by using the following expressions (Oyetunji, 2007)

(a) Mean Pair difference ($\bar{d}$)

$$(\bar{d}) = \sum \frac{(\text{Numerical data} - \text{Experimental data})}{\text{No. of paired test samples}} \dots\dots\dots (2.7)$$

(b) Variance of Pair difference

$$\text{Var}(d) = \frac{\sum d^2 - \frac{(\text{Numerical data} - \text{Experimental data})^2}{\text{No. of Paired test samples}}}{\text{No of paired test samples} - 1} \dots\dots\dots (2.8)$$

(c) Variance of mean of pair difference $\text{Var}(\bar{d})$

$$\text{Var}(\bar{d}) = \frac{\text{Var}(d)}{\text{No of paired test samples}} \dots\dots\dots (2.9)$$

(d) Standard deviation of mean of pair difference (sd)

$$\text{Sd} = \sqrt{\text{Var}(\bar{d})} \dots\dots\dots (2.10)$$

(e) Acceptable tolerance interval for a given confidence interval and numerical data

$$= \bar{d} + t_{(1-\alpha)} \text{Sd} \dots\dots\dots (2.11)$$

2.10.2 Correlation Analysis and Coefficient of Correlation

This is a statistical technique that is used to test for the relationship between two variables. The variables are said to be correlated when an increase or decrease in one variable is accompanied by an increase or decrease in the other. It is commonly used along with the regression analysis to measure how well the regression lines explain the variations of the dependent variable. If an increase in one variable corresponds to an increase in the other, the correlation is said to be positive. But if increase in one corresponds to decrease in the other, the correlation is referred to as negative. If there is no relationship between the two variables, they are said to be independent (Dass, 2005).

The following relations are methods used to determine simple correlation:

(i) Karl Pearson's coefficient of correlation

$$P_{xy} = \frac{Cov(X,Y)}{\sigma_x \sigma_y} \dots\dots\dots(2.12)$$

Where: $-1 \leq P_{xy} \leq 1$ and

$$Cov(x,y) = \frac{1}{n} \sum_{i=1}^n (x - \bar{x})(y - \bar{y}) \dots\dots\dots(2.13)$$

Where:

$$Cov(x,y) = \text{Covariance of X and Y} \dots\dots\dots(2.14)$$

σ_x = Variance of X

σ_y = Variance of Y

P_{xy} = Correlation Coefficient

$\bar{x}$ = Mean of X

$\bar{Y}$ = Mean of Y

X = Experimental value

Y = Numerical value

N = No. of pair test samples

(ii) Pearson's rank correlation coefficient

$$R = 1 - \frac{6 \sum d^2}{n(n^2 - 1)} \dots\dots\dots (2.15)$$

(iii) Coefficient correlation

$$R = \sqrt{1 - \frac{\sum (Y_o - Y_e)^2}{\sum (Y_o - \bar{Y})^2}} \dots\dots\dots (2.16)$$

2.10.3 Standard Error of Prediction

This is the deviation of the predicted value from the observed value. It is given by:

$$E_{YX} = \sqrt{\frac{\sum (Y - Y_r)^2}{n}} \dots\dots\dots (2.17)$$

Where:

Y = the actual value (Observed)

Y_r = the predicted value (Dass, 2005)

The Karl Pearson's equation for calculating the standard error of the predicted numerical data (Y) is given

as;

$$SE_{y-x} = \sqrt{\left[\frac{1}{n(n-2)} \right] n \sum y^2 (\sum Y)^2 - \frac{[nExy - (Ex)(Ey)]^2}{nEx^2 - (Ex)^2}} \dots\dots (2.18)$$

Where:

Y = Numerical data

X = Experimental data

N = No. of pair test samples

2.11 PAST RESEARCHES ON MODELLING OF MECHANICAL

PROPERTIES OF MATERIALS AND EXPERIMENTAL VALIDATION

Quite a number of researches have been carried out on modelling of mechanical properties of various types of materials, steels inclusive. Some of the researches centered on improving the mechanical properties, while various types of casting processes and other production routes have also been considered for modelling. However, a vast majority of processes are yet to be assessed for study.

Oyetunji (2009) modelled the impact properties of grey cast iron produced from Steel and CO₂ moulds. Oyetunji and Adebisi (2008) developed software for rapid estimation of corrosion rate of austempered ductile iron in corrosive media. Oyetunji (2007) studied extensively on modeling mechanical properties of grey cast iron by using a statistical method of multiple regression analysis to develop the models. He then used pair t-test, correlation coefficient and standard error principles to validate the model developed before developing software that can be used to rapidly estimate the properties. Ndaliman, (2006) carried out an assesment of mechanical properties of medium carbon steel under

Simecek and Hajduk, (2007) used 3D finite elements method to study rolling products after cooling from exit rolling temperature in their work titled "Prediction of mechanical properties of hot rolled steel products". They found out that the comparison of MECHP calculations with measured process data (water cooling and subsequent air cooling of hot rolled narrow plate and wire) shows correspondence that is satisfactory for use in control of process cooling technology. The result of the verification showed that the software tool, MECHP is implementable. However, in the case of Myllykoski, et al (1996) on the "Development of prediction model for mechanical properties of batch annealed thin steel strip by using artificial neural network modelling" they confirmed that it is possible to predict accurately the mechanical properties of thin steel strip by using ANN modelling and the measurement data of the process. They also concluded that the prediction can be used to evaluate the effect of process parameters while the controllable parameters can be changed in such a way that the process yield the desired mechanical properties.

A phase-field modelling of the thermo-mechanical properties of carbon steels was carried out in Jin Seol, et al (2000)'s work. while Hua DING, et al (2006) studied the microstructures and mechanical properties of Fe-Mn-(Al,Si) TRIP/TWIP steels. "Statistical modelling of mechanical tensile properties of steels by using neural network and multivariate data analysis" was studied by Dumortier, and Leher, (1999). Sterjovski, et al (2005) used artificial neural networks for modelling the mechanical properties of steels in various applications. He used the model developed to predict:

- (i) Impact toughness of quenched and tempered pressure vessel steel;
- (ii) Hardness of the simulated Heat Affected Zone (HAZ) in pipeline and tap fitting steels; and

(iii) Hot ductility and hot strength of various alloys steels over temperature range for strand and slab straightening in continuous casting process. It was concluded that the developed model have the capacity to eliminate the need for expensive experimental investigation in areas like testing, manufacturing process, inspectioning and repair.

CHAPTER THREE



3.0 RESEARCH METHODOLOGY

3.1 MATERIALS

The rolled ribbed medium carbon steel rods used for the research work were obtained from Ajaokuta Steel Company limited, Ajaokuta, Kogi, State and Delta Steel Company, Aladja, Delta State. The rods used were 12mm, 16mm, 20mm and 25mm in diameter. Other materials included abrasive papers, emery cloth, and diamond paste, water as coolant, etchant, cotton wool and desiccator.

3.2 EQUIPMENT

A mass spectrometric analyzer was used to determine the chemical composition of the samples. An Istron Universal tensile testing machine and digital hardness tester were used to test for the tensile properties and hardness measurement respectively. A V-notch pendulum-type impact testing machine was used to test for the toughness. A lathe machine with coolant was used to machine the samples to various standard test specimens used for the experimental properties estimation. Other equipment used in the research work was a hawksaw to cut hardness test sample and electric table grinder to grind the surface. Grinding and polishing machines were also used to prepare the specimen's surfaces for microstructural examination which was obtained with aid of high magnification optical microscope with digital camera attached to take the micrograph.

3.3 CUT OFF AND MACHINE OPERATIONS

The samples were machined into various standard tests specimens for hardness, tensile properties and impact tests. The standard tensile test specimens were prepared according to specification of 130mm long with a gauge length of 70mm and the hardness samples were cut into about 20mm long both as shown in Figures 3.1 and 3.2. The specimens for impact test were machined into standard samples in conformity with the charpy impact machine specification. The drawing is as shown in Figure 3.3

Precautions were taken throughout the machining operations to ensure that the lathe machine coolant was continuously applied to the tool bit of the machine in order to prevent excessive heating of the samples and provide lubrication. This was important in order not to alter the original structures and properties of the materials. And to ensure accuracy of dimensions, measurements were carried out with the aid of vernier caliper and micrometer screw gauge.

The Tables 3.1 shows the chemical compositions of the rolled ribbed medium carbon steels used in this research and predictors (independent variables) for the modelling.

Table 3.1: Chemical Compositions of the Rolled Ribbed Medium Carbon**Steels used in the Research and Predictors (Independent Variables)**

X ₁ Diameter (mm)	X ₂ %C	X ₃ %Mn	X ₄ %Si	X ₅ %P	X ₆ %S	X ₇ %Cr	X ₈ %Ni	X ₉ %Cu	X ₁₀ %Co	X ₁₁ %W	X ₁₂ %Fe
12	0.359	0.72	0.171	0.016	0.015	0.78	0.08	0.221	0.038	0.157	97.443
12	0.357	0.63	0.101	0.016	0.015	0.69	0.08	0.276	0.016	0.158	97.661
12	0.355	0.74	0.18	0.016	0.014	0.72	0.07	0.249	0.024	0.158	97.474
16	0.358	0.62	0.18	0.041	0.039	0.019	0.075	0.25	0.031	0.148	98.239
16	0.359	0.6	0.19	0.039	0.038	0.021	0.074	0.27	0.028	0.147	98.234
16	0.362	0.67	0.2	0.038	0.042	0.017	0.074	0.26	0.019	0.151	98.167
20	0.389	0.68	0.16	0.042	0.031	0.015	0.026	0.251	0.016	0.121	98.269
20	0.391	0.67	0.18	0.04	0.028	0.018	0.021	0.248	0.014	0.11	98.28
20	0.39	0.61	0.17	0.041	0.031	0.011	0.072	0.253	0.022	0.119	98.281
25	0.422	0.691	0.224	0.031	0.042	0.01	0.021	0.248	0.018	0.158	98.135
25	0.415	0.685	0.219	0.03	0.041	0.01	0.02	0.248	0.017	0.156	98.158
25	0.418	0.72	0.222	0.032	0.038	0.01	0.02	0.252	0.018	0.158	98.112

3.4 DETERMINATION OF MECHANICAL PROPERTIES OF ROLLED MEDIUM CARBON STEEL

The following mechanical properties (harness, tensile strength, breaking strength, yield strength and impact toughness) were experimentally determined on the various test specimens earlier prepared.

3.4.1 Tensile Tests

The test was performed in accordance with (Oyetunji 2007), and Istron universal tester machine operational manual. Each test piece shown in Figure 3.1 was clamped/mounted on the machine at the jaws-one end stationary and the other movable. The machine was then operated which pulled at constant rate of extension. The total elongation/extension suffered and the corresponding applied load were automatically recorded by the computer systems attached to the machine until the sample ruptured. A comprehensive result was

then obtained from the computer to include the graph and other parameters. The corresponding stress and strain were calculated and the result for the tensile tests were contained in Tables 5.3 – 5.5 and 5.9 – 5.11

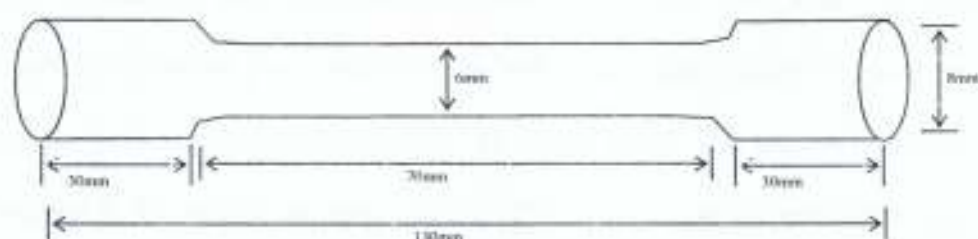


Figure 3.1: Standard Tensile Test Piece

3.4.2 Hardness Test

The hardness tests were performed with the aid of a digital Rockwell hardness tester in accordance with (Oyetunji, 2007), and the machine operational procedure. During the process, the surface of all the test specimens as shown in Figure 3.2 in which an indentation was to be made were ground using 200nm grinding papers to make them flat and smooth. A diamond indenter under the application of 60 KN was pressed into the surface. The results were displayed on the machine scale and the average was taken. The same procedure was applied to all the samples. The results of the hardness measurement are shown in Tables 5.1 – 5.2 and 5.7 – 5.8

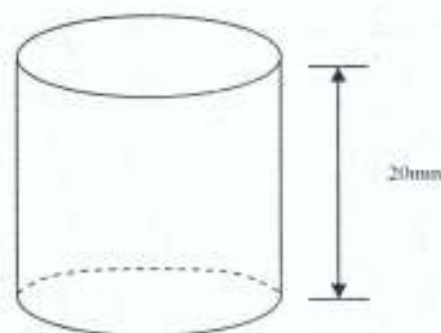


Figure 3.2: Hardness Test Piece

3.4.3 Impact Test

The impact tests were performed using V-notch pendulum-type impact testing machine. Each test piece was held horizontally on a vice attached to the impact testing machine in such a way that the notched side faced the approaching hammer. And with specimen properly mounted, the hammer was released from a predetermined height to strike the specimen. After the striking, the hammer moved to a height which was then measured as the energy absorbed by the specimen upon fracture. The energy was read on the energy scale of the machine. Each experimental result of the test recorded was an average of the least three repetitions. The impact test results are as shown in Tables 5.6 and 5.12.

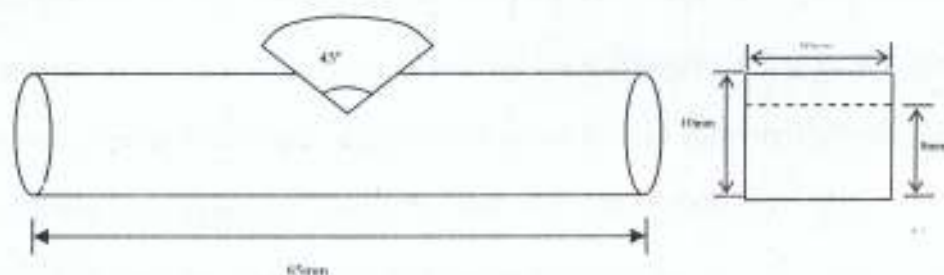


Figure 3.3: V-notch Impact Test Piece

3.5 METALLOGRAPHIC ANALYSIS

This stage involved the usual procedure of cutting, grinding, polishing, etching, micro-examination and photo-microscopy (micrograph) of the tests specimens. All prescribed conditions were observed during the processes.

3.5.1 Selection of Samples

Specimens were obtained from portion of the work-piece as a representation of the samples. They were cut into small sizes for holding during grinding and polishing. Water as coolant was continuously applied to lubricate the specimens and prevent any alteration in the original structures.

3.5.2 Grinding

Each of the specimens was ground on an electric table grinder with an abrasive wheel to obtain an averagely flat surface. After this, the specimens were washed off with running water to remove any loose grit. The specimens were thereafter ground on a series of silicon carbide papers of increasing fineness beginning from 200-grit, 300-grit, 400-grit and finally 600-grit papers. The usual standardized procedure of rotating through 90° when changing from one grade of paper to the next was observed. Water was continuously added during the operations. Excessive deformation of the surface was however prevented during the grinding by applying only light pressure on the specimen. After successful grinding, i.e. removal of all forms of scratches of the previous paper marks, the specimens were washed under running water in readiness for the next stage.

3.5.3 Polishing

This was carried out with the aid of emery cloth attached to a rotating disc machine to remove all the remaining scratches. A diamond paste as polishing agent was applied and polishing was continued until a mirror-finish appearance was obtained. The specimens were then covered with cotton wool and put in desicator to prevent corrosion by the

environmental air before etching. Care was taken to ensure very clean cloths and environment to avoid contamination during the process.

3.5.4 Etching

This was to assist in revealing the structures at the surface layer of the specimens. Swabbing was done for 3 seconds after which the surface was rinsed under running water, then methylated spirit to remove water stain from the surface and finally dried in warm air. The etching was done with the aid of cotton wool using Nital (i.e. 2% of Nitric acid and 98% ethanol).

3.5.5 Microstructural Examination

The specimens were viewed with the aid of a metallurgical microscope of 800x magnifications with digital camera and computer system attached. The snapped pictures of microstructures of the observed microscopes before etching and at 400x and 800x magnifications after etching were taken and downloaded into the computer attached, then printed. The printed pictures are as shown in Plates 1-12.

4.0 MODEL DEVELOPMENT, VALIDATION AND DEVELOPMENT OF COMPUTER SOFTWARE FOR THE MODEL

4.1 MODEL DEVELOPMENT

Statistical analysis was used to develop the models.

4.1.1 Statistical analysis

The results of the three tests namely tensile, hardness and impact were analyzed statistically by using a routine for correlation, that is, multiple regression analysis. The computation of the multiple regression parameters (coefficients) were obtained with the aid of computer in a stepwise technique. The package used was statistical package for social science (SPSS). *Thereafter, the correlation between the predictors (independent variables) such as sample sizes, percentage carbon, percentage manganese, percentage silicon, percentage phosphorous, percentage sulphur, percentage chromium, percentage nickel, percentage copper, percentage cobalt, percentage tungsten and percentage iron with the tensile strength at maximum load, tensile strength at break, yield strength, impact energy and hardness were carried out. They all indicate good correlation.*

The multiple regression analysis in accordance with (Oyetunji, 2007) was used to determine the respective relations for the tensile properties, impact energy and hardness with and without percentage iron for the four materials samples used.

In formulating these models, the following conditions were assumed to have existed:

- 1 Other elements in the materials were assumed insignificant.

- 2 The materials samples were as-rolled from the companies.
- 3 There was normal heating regime of the billets in the Re-heating furnace.
- 4 The system was under continuous rolling production.
- 5 There was no over tension and looping on the rolling line i. e. normal rolling speed.
- 6 Similar rolling scheme was used.
- 7 Normal water pressure.

The equations of the developed models that gave the estimated mechanical properties of the rolled ribbed bars are shown in equations 4.1 to 4.12 which were used to derive/calculate the numerical data shown in Tables 5.1 to 5.12.

MODELS TYPE-I (WITH IRON)

A₁: TRANSVERSE HARDNESS VALUE (THV)

$$\begin{aligned} \text{THV}_1 = & -8761.045 - 3.121\text{Dia.} + 368.952\%\text{C} + 90.524\%\text{Mn} + 63.113\%\text{Si} - 1179.607\%\text{P} \\ & - 497.482\%\text{S} + 52.638\%\text{Ni} - 19.221\%\text{Cu} + 281.419\%\text{Co} + 242.816\%\text{W} \\ & + 88.434\%\text{Fe} \quad \dots\dots\dots (4.1) \end{aligned}$$

B₁: LONGITUDINAL HARDNESS VALUE (LHV)

$$\begin{aligned} \text{LHV}_1 = & -10185.1 - 3.918\text{Dia.} + 478.255\%\text{C} - 94.675\%\text{Mn} + 217.623\%\text{Si} + 454.022\%\text{P} \\ & - 2576.025\%\text{S} + 129.133\%\text{Ni} - 858.781\%\text{Cu} - 1436.090\%\text{Co} + 1245.566\%\text{W} \\ & + 104.783\%\text{Fe} \quad \dots\dots\dots (4.2) \end{aligned}$$

C₁: TENSILE STRENGTH AT MAXIMUM LOAD (TS@L_{Max})

$$\begin{aligned} TS@L_{Max} = & 94603.105 - 40.236Dia. + 8869.178\%C - 4228.685\%Mn + 2683.913\%Si \\ & + 42726.779\%P - 18345.1\%S - 2392.061\%Ni - 6662.409\%Cu \\ & - 20887.8\%Co + 12707.265\%W - 965.300\%Fe \dots (4.3) \end{aligned}$$

D₁: TENSILE STRENGTH AT BREAK (TS@Break)

$$\begin{aligned} TS@Break = & 29685.912 - 24.84Dia. + 6672.319\%C - 2449.659\%Mn + 1983.252\%Si \\ & + 23344.305\%P - 15350.3\%S - 1043.603\%Ni - 5179.974\%Cu \\ & - 13607.1\%Co + 8505.157\%W - 303.993\%Fe \dots (4.4) \end{aligned}$$

E₁: YIELD STRENGTH (YS)

$$\begin{aligned} YS = & 18771.779 - 47.062 Dia. + 6806.016\%C - 2642.321\%Mn + 2267.215\%Si \\ & + 26006.971\%P - 17867.7\%S - 1080.794\%Ni - 6223.144\%Cu - 15487.0\%Co \\ & + 11112.811\%W - 190.116\%Fe \dots (4.5) \end{aligned}$$

F₁: IMPACT STRENGTH (IS)

$$\begin{aligned} IS = & 49533.516 + 18.746Dia. - 3143.437\%C - 1210.22\%Mn + 293.275\%Si \\ & + 10289.641\%P - 2665.421\%S - 596.001\%Ni - 1908.336\%Cu - 5937.968\%Co \\ & + 1756.776\%W - 486.748\%Fe \dots (4.6) \end{aligned}$$

MODELS TYPE-II (WITHOUT IRON)

A₂: TRANSVERSE HARDNESS VALUE (THV)

$$\begin{aligned} THV_2 = & 79.057 - 3.20Dia. + 292.132\%C + 1.789\%Mn - 24.753\%Si - 1259.459\% \\ & - 598.514\%S - 89.020\%Cr - 36.112\%Ni - 108.391\%Cu + 192.169\%Co \\ & + 160.011\%W \dots (4.7) \end{aligned}$$

B₂: LONGITUDINAL HARDNESS VALUE (LHV)

$$\begin{aligned} \text{LHV}_2 = & 289.360 - 4.012\text{Dia.} + 387.232\%C - 199.816\%Mn + 113.513\%Si + 359.407\%P \\ & - 2695.735\%S - 105.478\%Cr + 23.974\%Ni - 964.437\%Cu - 1541.841\%Co \\ & + 1147.451\%W \quad \dots\dots\dots (4.8) \end{aligned}$$

C₂: TENSILE STRENGTH AT MAXIMUM LOAD (TS_{Max})

$$\begin{aligned} \text{TS}_{\text{max } 2} = & -1891.430 - 39.370\text{Dia} + 9707.708\% - 3260.090\%Mn + 3643.010\%Si \\ & + 43598.406\%P - 7242.3\%S + 971.700\%Cr - 1423.307\%Ni - 5689.067\%Cu \\ & - 19913.6\%Co + 13611.132\%W \quad \dots\dots\dots (4.9) \end{aligned}$$

D₂: TENSILE STRENGTH AT BREAK (TS_{@Break})

$$\begin{aligned} \text{TS}_{\text{@Break } 2} = & -702.189 - 24.569\text{Dia.} + 6936.389\%C - 2144.629\%Mn + 2285.292\%Si \\ & + 23618.798\%P - 15003.0\%S + 306.008\%Cr - 738.523\%Ni \\ & - 4873.448\%Cu - 13300.3\%Co + 8789.803\%W \quad \dots\dots\dots (4.10) \end{aligned}$$

E₂: YIELD STRENGTH (YS)

$$\begin{aligned} \text{YS}_2 = & -232.782 - 46.891\text{Dia.} + 6971.164\%C - 2451.557\%Mn + 2456.109\%Si \\ & + 26178.638\%P - 17650.5\%S + 191.376\%Cr - 889.998\%Ni - 6031.445\%Cu \\ & - 15295.1\%Co + 11292.827\%W \quad \dots\dots\dots (4.11) \end{aligned}$$

F₂: IMPACT STRENGTH (IS)

$$\begin{aligned} \text{IS}_2 = & 876.643 + 19.182\text{Dia.} - 2720.612\%C - 721.811\%Mn + 776.895\%Si \\ & + 10729.154\%P - 2109.332\%S + 489.975\%Cr - 107.512\%Ni - 1417.534\%Cu \\ & - 5446.725\%Co + 2212.546\%W \quad \dots\dots\dots (4.12) \end{aligned}$$

4.2 VALIDATION OF THE DEVELOPED MODELS

Statistical tests were used to validate the developed models. The experimental and numerical data of each property were subjected to the following statistical tests:

- (i) Paired t-tests
- (ii) Correlation Coefficient
- (iii) Standard Error of Prediction

4.2.1 Pair t-tests

This was done to confirm that there is no significant difference between the experimental and numerical values. A sample of the detail calculation of the variances, standard deviation and the intervals by using the paired t-tests were calculated as shown in Appendix I including the coefficient of correlation and standard error, while the summary of all the results obtained from the tests are as shown in Tables 4.2 to 4.13.

The tables used the following representations:

THV_1 = Transverse Rockwell Hardness value A of model with iron inclusive

LHV_L = Longitudinal Rockwell Hardness value A of model with iron inclusive

TSL_{MAX1} = Tensile Strength at maximum load of model with Iron inclusive

$TS_{@Break 1}$ = Tensile Strength at break of model with iron inclusive

YS_1 = Yield Strength of model with Iron inclusive

IS_1 = Impact Strength of model with Iron inclusive

THV_2 = Transverse Rockwell Hardness value A of model without iron

LHV_2 = Longitudinal Rockwell Hardness value A of model without iron

TSL_{MAX2} = Tensile Strength at maximum load of model without Iron

TS_{noBreak 2} = Tensile Strength at break of model without iron

YS₂ = Yield Strength of model without Iron

IS₂ = Impact Strength of model without Iron inclusive

4.2.2 Correlation Coefficient

This was used to determine the relationship between the experimental and numerical data obtained. The interpretation of the correlation results obtained was achieved by using the rule of thumb for interpreting coefficient of correlation shown in Table 4.1.

The correlation coefficient equation used was as shown in equation 4.18

Coefficient correlation $R = \sqrt{1 - \frac{\sum(Y_a - Y_c)^2}{\sum(Y_a - \bar{Y})^2}}$ (4.18)

Where:

Y_c = Predicted value;

Y_a = Experimental value;

$\bar{Y}$ = Average of Y_a and

The results obtained from the calculations were summarized and shown in Tables 4.8 to 4.13.

4.2.3 Standard Error of Prediction

This measures the amount of error in the prediction of the numerical data (Y) for an individual experimental data (X) of various mechanical properties of the rolled ribbed medium carbon steel samples investigated.

The equation used for calculating the standard error of the predicted numerical data (Y) is given as:

$$E_{y-x} = \sqrt{\frac{\sum (Y - Y_r)^2}{n}} \quad \dots\dots\dots (4.19)$$

Where:

Y = the Actual value (experimental value) and

Y_r = the Predicted value (Numerical value)

The results obtained were summarized and shown in Tables 4.8 to 4.13

4.2.4 Interpretation of Data

- (1) The results obtained showed that there was no significant difference between the two techniques used to determine the mechanical properties of the rolled ribbed medium carbon steel under investigation. The intervals for the sets of data (experimental and numerical) for all the mechanical tests carried out on the samples were very narrow.
- (2) The correlation coefficient (R) values of the two sets of data for all tests were within the range of 0.99-0.9999. This indicates that there was a very high positive correlation between the numerical and experimental data for all the tests (Aderoba, 1995). This also implies a perfect reliability of results from both numerical and experimental data for the mechanical tests (Oyetunji, 2007).
- (3) The standard errors between the numerical and experimental data for the tests carried out were very small. This means that the disparity of the values for the two sets of data were very small as well; therefore, there was no significant difference between the experimental and numerical techniques of mechanical properties estimation. Hence, the developed model is valid and reliable

Table 4.1: Rule of Thumb for interpreting the correlation Coefficient R (Aderoba, 1995)

Value of R	Interpretation
0.90 – 1.00	Very high correlation
0.70 – 0.90	High correlation
0.40 – 0.70	Moderate correlation
0.20 – 0.40	Low correlation
0 – 0.20	Slight correlation

Table 4.2: Pair t-test Analysis to Determine the Acceptable Confidence Interval Range of Transverse Rockwell Hardness

Value A of Rolled Ribbed Medium Carbon Steel.

Transverse Rockwell Hardness Value A of Rolled Ribbed Medium Carbon Steels	Pair Difference (d)	Square of Pair Difference (d ²)	Mean of Pair Difference ($\bar{d}$)	Variance of Pair Difference Var (d)	Mean of Variance of Pair Difference Var ($\bar{d}$)	Standard Deviation (Sd)	Confidence Interval (α)	Degree of Freedom t_v	Acceptable Interval ($\bar{d} + t_{(1-\alpha)} Sd$)	
									Upper Limit	Lower Limit
THV 1	0.50957	0.0222511	0.0425	0.00005569	0.00000464	0.0021543	99.9% = 0.999	4.44	0.0329	0.05207
THV 2	-0.03421	0.01035106	-2.8508E-3	9.3214E-4	7.7678E-5	8.8135E-3	99.9% = 0.999	4.44	-0.0420	0.0363

Table 4.3: Pair t-test Analysis to Determine the Acceptable Confidence Interval Range of Longitudinal Rockwell Hardness

Value A of Rolled Ribbed Medium Carbon Steel.

Longitudinal Rockwell Hardness Value A of Rolled Ribbed Medium Carbon Steels	Pair Difference (d)	Square of Pair Difference (d ²)	Mean of Pair Difference ($\bar{d}$)	Variance of Pair Difference Var (d)	Mean of Variance of Pair Difference Var ($\bar{d}$)	Standard Deviation (Sd)	Confidence Interval (α)	Degree of Freedom t_v	Acceptable Interval ($\bar{d} + t_{(1-\alpha)} Sd$)	
									Upper Limit	Lower Limit
LHV 1	-9.36546	8.7648	0.7805	0.1323	0.0110	0.105	99.9% = 0.999	4.44	-1.2467	-0.3143
LHV 2	-0.94834	0.91310227	-0.079	0.0762	6.350E-3	0.0797	99.9% = 0.999	4.44	-0.4329	0.2749

Table 4.4: Pair t-test Analysis to Determine the Acceptable Confidence Interval Range of Tensile Strength at maximum

Load of Rolled Ribbed Medium Carbon Steel.

Tensile Strength at Maximum Load of Rolled Ribbed Medium Carbon Steels	Pair Difference (d)	Square of Pair Difference (d ²)	Mean of Pair Difference ($\bar{d}$)	Variance of Pair Difference Var (d)	Mean of Variance of Pair Difference Var ($\bar{d}$)	Standard Deviation (Sd)	Confidence Interval (α)	Degree of Freedom t_v	Acceptable Interval ($\bar{d} \pm t_{\alpha/2, \alpha} Sd$)	
									Upper Limit	Lower Limit
TS@Lmax1	-6.2682	43.9937	-0.5224	3.7018	0.3085	0.5554	99.9% = 0.999	4.44	-2.988	1.9436
TS@Lmax2	-5.7626	32.4585	-0.4802	2.699	0.2249	0.4743	99.9% = 0.999	4.44	-2.5861	1.6257

Table 4.5: Pair t-test Analysis to Determine the Acceptable Confidence Interval Range of Tensile Strength at Break of

Rolled Ribbed Medium Carbon Steel.

Tensile Strength at break of Rolled Ribbed Medium Carbon Steels	Pair Difference (d)	Square of Pair Difference (d ²)	Mean of Pair Difference ($\bar{d}$)	Variance of Pair Difference Var (d)	Mean of Variance of Pair Difference Var ($\bar{d}$)	Standard Deviation (Sd)	Confidence Interval (α)	Degree of Freedom t_v	Acceptable Interval ($\bar{d} \pm t_{\alpha/2, \alpha} Sd$)	
									Upper Limit	Lower Limit
TS@Break 1	-5.4926	27.1483	-0.4577	2.2395	0.1866	0.432	99.9% = 0.999	4.44	-2.3758	1.4604
TS@Break 2	-4.9136	23.7880	-0.4095	1.98	0.165	0.406	99.9% = 0.999	4.44	-2.2121	1.3931

le 4.6: Pair t-test Analysis to Determine the Acceptable Confidence Interval Range of Yield Strength of Rolled Ribbed

Medium Carbon Steel.

Yield Strength of Rolled Ribbed Medium Carbon Steels	Pair Difference (d)	Square of Pair Difference (d ²)	Mean of Pair Difference ($\bar{d}$)	Variance of Pair Difference Var (d)	Mean of Variance of Pair Difference Var ($\bar{d}$)	Standard Deviation (Sd)	Confidence Interval (α)	Degree of Freedom t _v	Acceptable Interval ($\bar{d} \pm t_{(1-\alpha)} Sd$)	
									Upper Limit	Lower Limit
YS 1	1.116	32.6552	0.093	2.959	0.2466	0.4966	99.9% = 0.999	4,44	-2.1119	2.2979
YS 2	0.071	0.00119	0.00592	6.999E-5	5.833E-6	2.42E-3	99.9% = 0.999	4,44	-0.0048	0.0167

le 4.7: Pair t-test Analysis to Determine the Acceptable Confidence Interval Range of Impact Toughness of Rolled

Ribbed Medium Carbon Steel.

Impact Strength of Rolled Ribbed Medium Carbon Steels	Pair Difference (d)	Square of Pair Difference (d ²)	Mean of Pair Difference ($\bar{d}$)	Variance of Pair Difference Var (d)	Mean of Variance of Pair Difference Var ($\bar{d}$)	Standard Deviation (Sd)	Confidence Interval (α)	Degree of Freedom t _v	Acceptable Interval ($\bar{d} \pm t_{(1-\alpha)} Sd$)	
									Lower Limit	Upper Limit
IS 1	-2.094	3.692994	-0.1745	0.3025	0.02521	1.558E-1	99.9% = 0.999	4,44	-0.8796	0.5306
IS 2	-1.462	2.025088	-1.218E-1	1.679E-1	1.399E-2	1.183E-1	99.9% = 0.999	4,44	-0.6471	0.4035

Table 4.8: Correlation Coefficient and Standard Error Analysis of Transverse Rockwell Hardness Value A of Rolled Ribbed Medium Carbon Steel

TRANSVERSE HARDNESS VALUE (RHA) OF ROLLED RIBBED MEDIUM CARBON STEELS	CORRELATION COEFFICIENT OF MODELS	STANDARD ERROR OF MODELS	STANDARD ERROR OF SOFTWARE
THV1	0.9998	0.043	0.1414
THV2	0.9998	0.029	0.1616

Table 4.9: Correlation Coefficient and Standard Error Analysis of Longitudinal Rockwell Hardness Value A of Rolled Ribbed Medium Carbon Steel

LONGITUDINAL HARDNESS VALUE (RHA) OF ROLLED RIBBED MEDIUM CARBON STEELS	CORRELATION COEFFICIENT OF MODELS	STANDARD ERROR OF MODELS	STANDARD ERROR OF SOFTWARE
LHV1	0.9492	0.855	5.1355
LHV2	0.9948	0.276	0.3493

Table 4.10: Correlation Coefficient and Standard Error Analysis of Tensile Strength at maximum Load of Rolled Ribbed Medium Carbon Steel

TENSILE STRENGTH AT MAXIMUM LOAD OF ROLLED RIBBED MEDIUM CARBON STEELS	CORRELATION COEFFICIENT OF MODELS	STANDARD ERROR OF MODELS	STANDARD ERROR OF SOFTWARE
Tensile Strength @ max Load 1	0.99943	1.915	1.8100
Tensile Strength @ max Load 2	0.99958	2.705	1.6859

Table 4.11: Correlation Coefficient and Standard Error Analysis of Tensile Strength at Break of Rolled Ribbed Medium Carbon Steel

TENSILE STRENGTH AT BREAK OF ROLLED RIBBED MEDIUM CARBON STEELS	CORRELATION COEFFICIENT OF MODELS	STANDARD ERROR OF MODELS	STANDARD ERROR OF SOFTWARE
Tensile Strength @ Break 1	0.999788	1.504	1.5939
Tensile Strength @ Break 2	0.999814	1.408	1.4174

Table 4.12: Correlation Coefficient and Standard Error Analysis of Yield**Strength of Rolled Ribbed Medium Carbon Steel**

YIELD STRENGTH OF ROLLED RIBBED MEDIUM CARBON STEELS	CORRELATION COEFFICIENT OF MODELS	STANDARD ERROR OF MODELS	STANDARD ERROR OF SOFTWARE
Yield Strength 1	0.998058	2.721	1.9514
Yield Strength 2	0.9999995	0.01	1.7205

Table 4.13: Correlation Coefficient and Standard Error Analysis of Impact**Toughness of Rolled Ribbed Medium Carbon Steel**

IMPACT STRENGTH OF ROLLED RIBBED MEDIUM CARBON STEELS	CORRELATION COEFFICIENT OF MODELS	STANDARD ERROR OF MODELS	STANDARD ERROR OF SOFTWARE
Impact Strength 1	0.9997	5.548E-1	0.6062
Impact Strength 2	0.9999	4.109E-1	2.4763

4.3 DEVELOPMENT OF COMPUTER SOFTWARE FOR THE MODELS

The multiple linear regression equations obtained were used to develop the flow chart and algorithm. These were then used to develop software that facilitated the rapid implementation of the developed models.

4.3.1 Development of Algorithm and Flowchart

The flowchart and algorithm were developed for the models. The flowchart developed is as shown in Figure 4.1, while the user friendly VISUAL BASIC 6.0 package was used to develop the algorithm in a familiar manner as contained in Appendix III

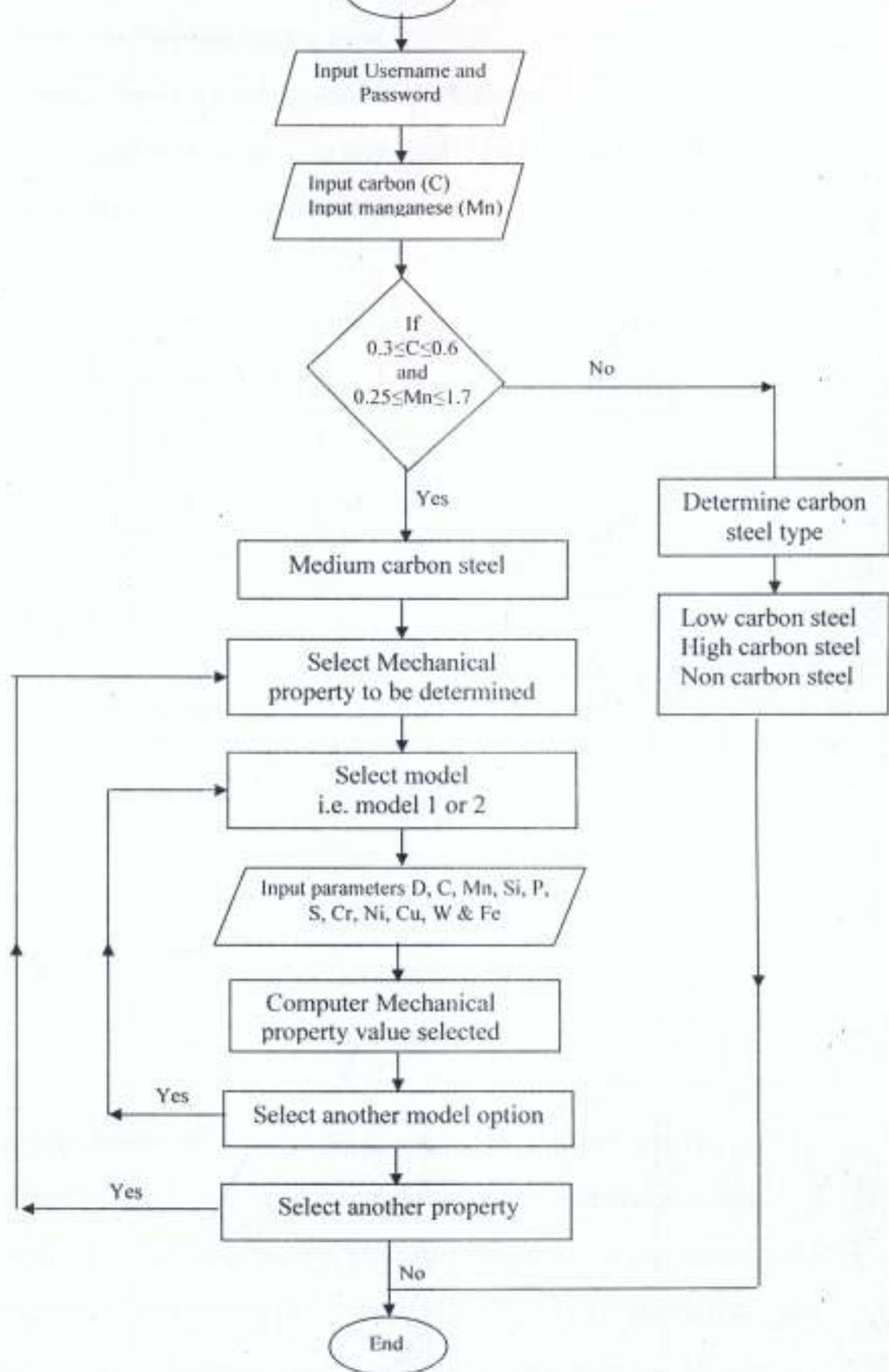


Figure 4.1: Flowchart of Developed Computer Software

4.3 2. Computer Software Development

The flowchart in Figure 4.1 and the algorithm in Appendix III developed for the two-type comprehensive models were both made use of for the computer software design/coding of the system. The following are the keys to the flowchart developed.



Data Input



Connector



Process



Decision



Terminator

The computer software titled “ROLLED STEEL INFORMATION SYSTEM 2010” was developed for quick access to theoretically estimate the mechanical properties of rolled ribbed medium carbon steel rods for various sizes ranging from diameter 12mm to diameter 25mm. ROLLED STEEL INFORMATION SYSTEM 2010 was designed in a friendly VISUAL BASIC 6.0 package to make it highly interactive and user friendly; through the use of controls such as textboxes, command buttons, frames and

the appropriate message boxes. The database and structure of the software is flexible but robust enough to accommodate as many data as storage capacity of the computer allows.

The flowchart in Figure 4.1 consists of the following sub-interfaces: the medium carbon steel material identification policy data; entry for property to be determined; entry for all the elements (Carbon, Manganese, Silicon, Nickel, Chromium, Phosphorus, Sulphur, Copper, Cobalt, Tungsten and Iron) and the section size of the rolled ribbed rod; selection of model type; computation of mechanical properties and the report sub-interfaces. The design/coding of the ROLLED STEEL INFORMATION SYSTEM 2010 software consists of the following phases: title, data entry, selection of property to be determined, model-type selection, computation and report phases.

(a) Title Phase

This interface welcomes the software user into the system. It contains the name of the software, the developer, the supervisor, the essence of the study and the department to which the developer belongs. It appears on the screen/monitor as shown in Figure 4.2.

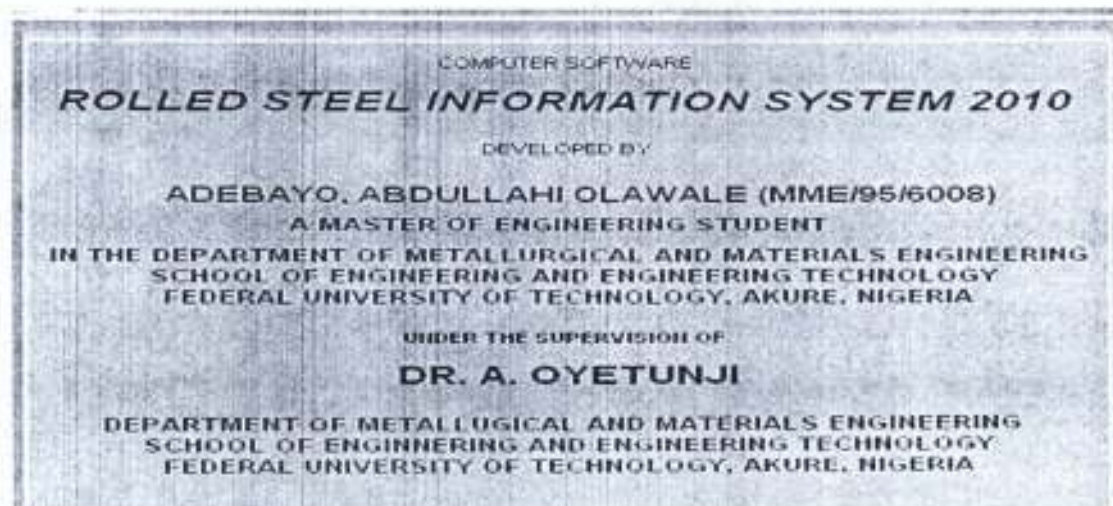


Figure 4.2: Title Phase of the Developed Software

(b) **Data Entry**

This interface enters data into the database. It contains the following sub-interfaces: the chemical compositions i. e. % chemical composition of carbon and manganese will be entered in this phase as shown in Figure 4.3 for materials identification.

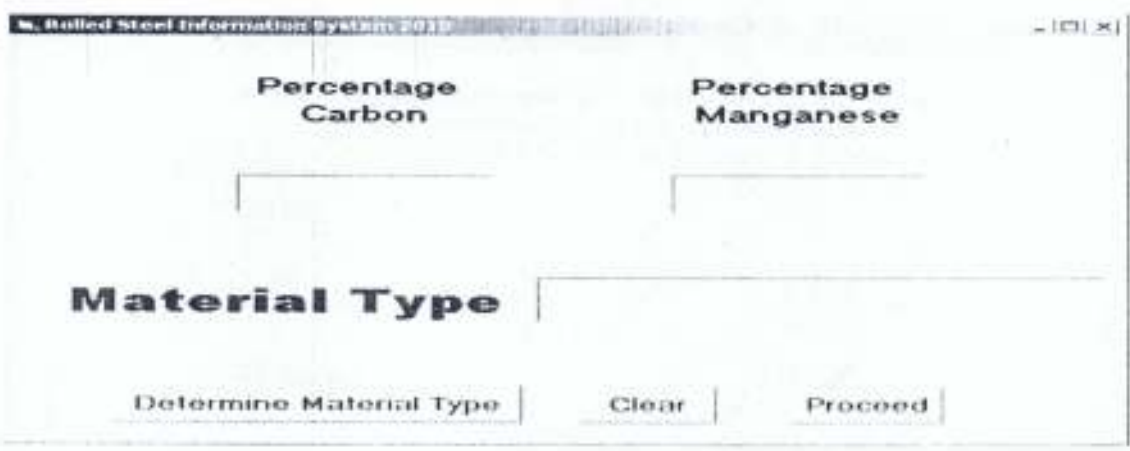


Figure 4.3: Material Identification Result Phase of the Developed Software

(c) **Materials Identification Policy Data**

From the input of % composition of carbon and manganese in the sub-interface, and mouse clicking the material type, the type of material the component is made up of will be displayed as obtained in the data entry phase in Figure 4.4. If the material type is medium carbon steel, it will proceed to the next stage. If not, the programmer will stop running/end.

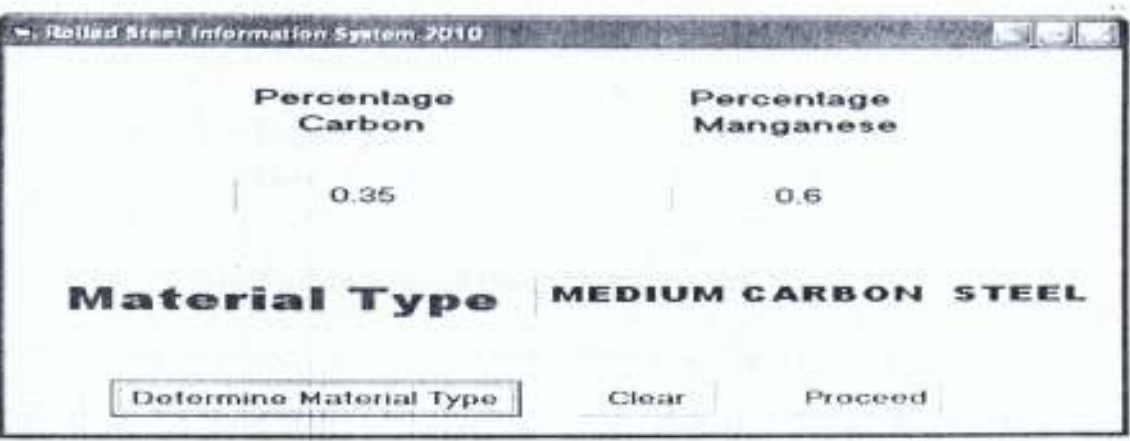


Figure 4.4: Material Identification Phase of the Developed Software

(d) Mechanical Properties Determination Policy

This phase contain the list of mechanical properties of the rolled ribbed medium carbon steel rod. The desired property to be determined is selected as displayed in Figure 4.5.

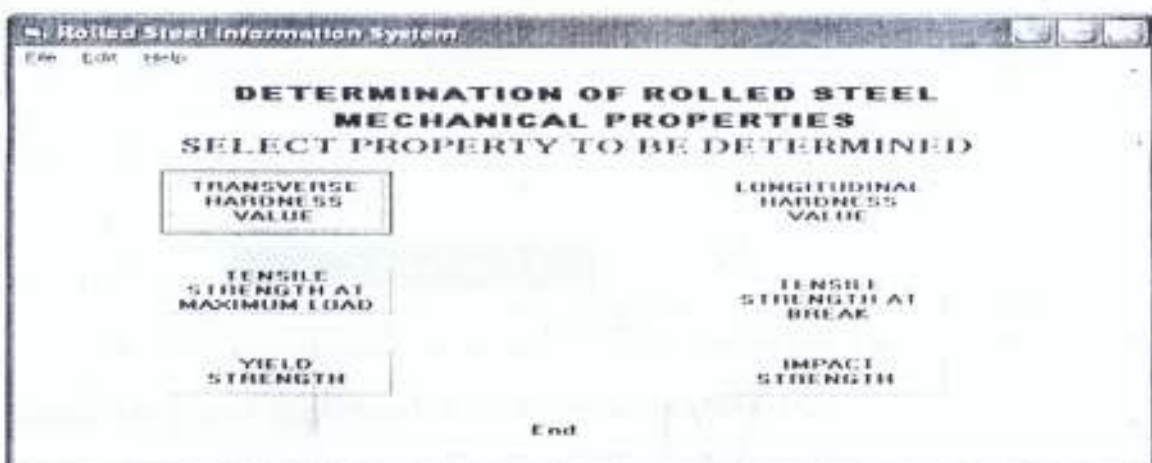


Figure 4.5: Property Determination Selection Phase of the Developed Software

In this research work, the following properties are to be computed when the chemical composition and diameter of samples are known:

- (i) THV = Transverse Rockwell Hardness value A
- (ii) LHV = Longitudinal Rockwell Hardness value A
- (iii) TSL_{MAX} = Tensile Strength at maximum load
- (iv) $TS_{@break}$ = Tensile Strength at break
- (v) YS = Yield Strength
- (vi) IS = Impact Strength

(e) Data Entry for Mechanical Property Estimation

Entry of the percentage compositions of the elements (Carbon, Manganese, Silicon, Phosphorus, Sulphur, Nickel, Chromium, Copper, Cobalt, Tungsten and Iron) and the section size of the rod are made as shown in Figure 4.6. This interface gives room for

all data entry to be made before proceeding to the next sub-interface, which is the model type determination policy.



Figure 4.6: Data Entry Phase of the Developed Software

(f) Selection of Model-type Policy

This enters the model type (either model type 1 or model type 2) for which the property is to be computed. This entering devise is very flexible and versatile as either of the two is selected by just clicking on the desired model type while the other automatically becomes deactivated as shown in Figure 4.7. This interface leads to report menu.



Figure 4.7: Model-Type Selection Phase of the Developed Software

This interface report the result of the mechanical properties determined for rolled ribbed medium carbon steel of a particular model-type when instructed to compute by clicking on compute the selected mechanical property as shown in the Figure 4.8.

Select Model	Model 1		Model 2	
Diameter	Percentage Carbon	Percentage Manganese	Percentage Silicon	
12	0.355	72	1.21	
Percentage Phosphorus	Percentage Sulphur	Percentage Chromium	Percentage Nickel	
0.016	0.015	78	0.06	
Percentage Copper	Percentage Cobalt	Percentage Tungsten	Percentage Iron	
221	0.08	157		
		49.603829		
Compute Transverse Hardness Value		Select Another Property	Clear	Exit

Figure 4.8: Report Menu Phase of the Developed Software

The report menu provides the following results for:

THV_1 = Transverse Rockwell Hardness value A of model with iron inclusive

LHV_1 = Longitudinal Rockwell Hardness value A of model with iron inclusive

TSL_{Max1} = Tensile Strength at maximum load of model with Iron inclusive

$TS_{@Break1}$ = Tensile Strength at break of model with iron inclusive

YS_1 = Yield Strength of model with Iron inclusive

IS_1 = Impact Strength of model with Iron inclusive

THV_2 = Transverse Rockwell Hardness value A of model without iron

LHV_2 = Longitudinal Rockwell Hardness value A of model without iron

TSL_{Max2} = Tensile Strength at maximum load of model without Iron

$TS_{@Break2}$ = Tensile Strength at break of model without Iron

YS_2 = Yield Strength of model without Iron

IS_2 = Impact Strength of model without Iron

4.3.3 Computer Requirements

The type of computer hardware requirements/specifications for the developed

ROLLED STEEL INFORMATION SYSTEM 2010 is a personal computer Pentium 2 and above or Laptop with at least 64 MB RAM, Microsoft Windows 98/NT/2000/XP and between 64 MB and 512 MB hard disk free space.



5.0 RESULTS AND DISCUSSIONS

5.1 RESULTS

The results of the experimental mechanical properties of the rolled ribbed medium carbon steels determined experimentally, their numerical values for models type I and II as well as the software computed values for models type 1 and 2 are presented in Tables 5.1 to 5.12. These include the Tensile Strength at maximum load, Tensile Strength at break, Yield Strength, Transverse Rockwell Harness value A, Longitudinal Rockwell Hardness value A and Impact Strength all for both with and without iron which were as follows:

Table 5.1: Transverse Rockwell Hardness Value A with Iron (Experimental Data, Numerical Data and Computer Software Result) of Rolled Ribbed Medium Carbon Steel

S/No.	Dia. (mm)	EXP VALUE	NUM VALUE 1	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)	SOFT WARE VALUE 1	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)
A	12	49.6	49.64368	0.04368	0.00219	49.64	0.04	0.0016
B	12	48.57	48.6138	0.0438	0.00192	48.61	0.04	0.0016
C	12	48.98	49.02357	0.04357	0.00190	49.92	0.04	0.0016
D	16	52.25	52.29407	0.04407	0.00194	52.26	0.01	0.001
E	16	52.33	52.37405	0.04405	0.00194	52.34	0.01	0.001
F	16	52.3	52.344	0.044	0.00194	52.34	0.04	0.0016
G	20	47.45	47.49427	0.04427	0.00196	47.49	0.04	0.0016
H	20	49.93	49.97425	0.04425	0.00196	50.07	0.14	0.28
I	20	47.94	47.98426	0.04426	0.00196	47.98	0.04	0.0016
J	25	54.05	54.09428	0.04428	0.00196	54.09	0.04	0.0016
K	25	53.5	53.52508	0.02508	0.00063	53.52	0.02	0.0004
L	25	53.72	53.76426	0.04426	0.00196	53.76	0.04	0.0016
SUM TOTAL		610.63	611.129	0.50957	0.02225	611.12	0.5	0.2934

Table 5.2: Longitudinal Rockwell Hardness Value A with Iron (Experimental Data, Numerical Data and Computer Software Result) of Rolled Ribbed Medium Carbon Steel

S/No.	Dia. (mm)	EXP VALUE	NUM VALUE 1	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)	SOFT WARE VALUE 1	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)
A	12	49.15	49.14141	-0.00859	0.00008	48.42	-0.73	0.5329
B	12	49.93	49.20732	-0.72268	0.52516	49.20	-0.73	0.5329
C	12	49.14	48.42142	-0.71588	0.51248	45.16	-3.98	15.8404
D	16	50.65	49.9267	-0.7233	0.52316	49.68	-0.97	0.9409
E	16	42.1	41.3747	-0.7253	0.52606	40.68	-1.42	2.0164
F	16	47.8	47.06875	-0.73125	0.53473	46.83	-0.97	0.9409
G	20	44.7	43.91612	-0.78388	0.61447	43.49	-1.21	1.4641
H	20	50.03	49.24212	-0.78788	0.62076	48.82	-1.21	1.4641
I	20	47.9	47.11412	-0.78588	0.61761	46.69	-1.21	1.4641
J	25	51.55	50.70199	-0.84801	0.71912	50.05	-1.50	2.25
K	25	51.03	49.33719	-1.69281	2.86561	48.67	-2.36	5.5696
L	25	51.24	50.4	-0.84	0.7056	49.74	-1.50	2.25
SUM TOTAL		585.22	574.8518	-9.36546	8.76482	567.43	-17.69	35.2663

Table 5.3: Tensile Strength at Maximum Load with Iron (Experimental Data, Numerical Data and Computer Software Result) of Rolled Ribbed Medium Carbon Steel

S/No.	Dia. (mm)	EXP VALUE	NUM VALUE 1	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)	SOFT WARE VALUE 1	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)
A	12	602.84	602.8748	0.0348	0.001211	602.88	0.04	0.0016
B	12	673.18	673.2152	0.0352	0.00124	673.22	0.08	0.0064
C	12	637.875	637.9101	0.0351	0.00123	637.91	0.03	0.0009
D	16	590.16	590.1933	0.0333	0.00111	590.19	0.03	0.0009
E	16	567.26	567.2934	0.0334	0.00112	567.29	0.03	0.0009
F	16	578.71	578.7433	0.0333	0.00111	578.74	0.03	0.0009
G	20	638.06	638.0925	0.0325	0.00106	638.09	0.03	0.0009
H	20	644.67	644.7026	0.0326	0.00062	644.70	0.03	0.0009
I	20	641.365	641.3974	0.0324	0.00105	641.40	0.03	0.0009
J	25	772.72	772.7505	0.0305	0.00093	772.75	0.03	0.0009
K	25	673.87	667.2381	-6.6319	43.98210	667.24	-6.63	43.9569
L	25	723.295	723.3256	0.0306	0.00094	723.33	0.03	0.0009
SUM TOTAL		7744.005	7737.7368	-6.2682	43.99371	7737.74	-6.24	43.973

Table 5.4: Tensile Strength at Break with Iron (Experimental Data, Numerical Data and Computer Software Result) of Rolled Ribbed Medium Carbon Steel

S/No.	Dia. (mm)	EXP VALUE	NUM VALUE 1	PAIR DIFF (d)	SQUARE OF PAIR DIFF. (d ²)	SOFT WARE VALUE 1	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)
A	12	469.84	469.8181	-0.0219	0.00048	469.82	-0.02	0.0004
B	12	494.83	494.8075	-0.0225	0.00051	494.81	-0.02	0.0004
C	12	482.335	482.3126	-0.0224	0.00050	482.31	-0.03	0.0009
D	16	473.55	473.5249	-0.0251	0.00063	473.53	-0.02	0.0004
E	16	448.99	448.9648	-0.0252	0.00064	448.96	-0.03	0.0009
F	16	461.27	461.2445	-0.0255	0.00065	461.24	-0.03	0.0009
G	20	551.84	551.8129	-0.0271	0.00073	551.81	-0.03	0.0009
H	20	579.78	579.753	-0.027	0.00073	579.75	-0.03	0.0009
I	20	565.81	565.7831	-0.0269	0.00072	565.78	-0.03	0.0009
J	25	671.14	671.1103	-0.0297	0.00088	671.11	-0.03	0.0009
K	25	611.87	606.6603	-5.2097	27.14097	606.66	-5.21	27.1441
L	25	641.505	641.4754	-0.0296	0.00088	641.48	-0.03	0.0009
SUM TOTAL		6452.78	6447.269	-5.4926	27.14832	6447.26	-5.49	27.152

Table 5.5: Yield Strength with Iron (Experimental Data, Numerical Data and Computer Software Result) of Rolled Ribbed Medium Carbon Steel

S/No.	Dia. (mm)	EXP VALUE	NUM VALUE 1	PAIR DIFF (d)	SQUARE OF PAIR DIFF. (d ²)	SOFT WARE VALUE 1	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)
A	12	452.713	453.099	0.387	0.1497	452.67	-0.043	0.001849
B	12	486.313	486.6994	0.3864	0.1493	486.27	-0.043	0.001849
C	12	469.512	469.8983	0.3863	0.1492	469.47	-0.042	0.001764
D	16	445.639	446.1697	0.5307	0.2816	445.59	-0.049	0.002401
E	16	406.734	407.2647	0.5307	0.2816	406.69	-0.044	0.001936
F	16	426.187	426.7181	0.5311	0.2821	426.14	-0.047	0.002209
G	20	406.734	407.4086	0.6746	0.4551	406.69	-0.044	0.001936
H	20	424.418	425.0925	0.7645	0.4550	424.37	-0.048	0.002304
I	20	415.576	416.2504	0.6744	0.4548	415.53	-0.046	0.002116
J	25	459.186	460.0409	0.8549	0.7309	459.14	-0.046	0.002116
K	25	397.892	392.5237	-5.3683	28.8186	391.63	-6.262	31.2126
L	25	428.839	429.6937	0.8567	0.7288	428.79	-0.049	0.002401
SUM TOTAL		5219.743	5220.86	1.116	32.6552	5212.98	-6.763	39.2355

Table 5.6: Impact Strength with Iron (Experimental Data, Numerical Data and Computer Software Result) of Rolled Ribbed Medium Carbon Steel

S/No.	Dia. (mm)	EXP VALUE	NUM VALUE 1	PAIR DIFF (d)	SQUARE OF PAIR DIFF. (d ²)	SOFT WARE VALUE 1	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)
A	12	84	83.98203	-0.018	0.000324	83.98	-0.02	0.0004
B	12	100	99.98198	-0.018	0.000324	99.98	-0.02	0.0004
C	12	100	99.98202	-0.018	0.000324	99.98	-0.02	0.0004
D	16	65	64.98351	-0.016	0.000256	64.98	-0.02	0.0004
E	16	52	51.98351	-0.016	0.000256	51.98	-0.02	0.0004
F	16	52	51.98352	-0.016	0.000256	51.98	-0.02	0.0004
G	20	50	49.98511	-0.015	0.000225	49.99	-0.01	0.0001
H	20	45	44.9851	-0.015	0.000225	44.98	-0.02	0.0004
I	20	48	47.98513	-0.015	0.000225	47.99	-0.01	0.0001
J	25	30	29.98721	-0.013	0.000169	29.99	-0.01	0.0001
K	25	42	40.07887	-1.921	3.690241	40.08	-1.92	3.6864
L	25	32	31.98721	-0.013	0.000169	31.99	-0.01	0.0001
SUM TOTAL		700	697.906	-2.094	3.693	697.90	-2.10	3.6896

Table 5.7: Transverse Rockwell Hardness Value A without Iron (Experimental Data, Numerical Data and Computer Software Result) of Rolled Ribbed Medium Carbon Steel

S/No.	Dia. (mm)	EXP VALUE	NUM VALUE 1	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)	SOFT WARE VALUE 2	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)
A	12	49.6	49.60383	0.00383	0.00001467	49.6	0.00	0.00
B	12	48.57	48.57385	0.00385	0.00001482	48.57	0.00	0.00
C	12	48.98	48.98384	0.00384	0.00001475	48.98	0.00	0.00
D	16	52.25	52.25537	0.00537	0.00002884	52.29	0.04	0.0016
E	16	52.33	52.33536	0.00536	0.00002873	52.37	0.04	0.0016
F	16	52.3	52.30537	0.00537	0.00002884	52.31	0.01	0.0001
G	20	47.45	47.45686	0.00686	0.00004786	47.46	0.01	0.0001
H	20	49.93	49.93685	0.00685	0.00004692	50.48	0.55	0.3025
I	20	47.94	47.94683	0.00683	0.00004665	47.95	0.01	0.0001
J	25	54.05	54.05867	0.00867	0.00005956	54.05	0.00	0.00
K	25	53.5	53.40028	-0.09972	0.00994408	53.40	-0.1	0.01
L	25	53.72	53.72868	0.00868	0.00007534	53.73	0.01	0.0001
SUM TOTAL		610.63	610.58578	-0.03421	0.01035106	611.19	0.57	0.3161

**Table 5.8: Longitudinal Rockwell Hardness Value A without Iron
(Experimental Data, Numerical Data and Computer Software Result)
of Rolled Ribbed Medium Carbon Steel**

No.	Dia. (mm)	EXP VALUE	NUM VALUE 1	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)	SOFT WARE VALUE 2	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)
	12	49.15	49.15433	0.00433	0.00001875	49.16	0.01	0.0001
	12	49.93	49.93433	0.00433	0.00001875	49.94	0.01	0.0001
	12	49.14	49.14436	0.00436	0.00001901	49.15	0.01	0.0001
	16	50.65	50.65589	0.00589	0.00003469	50.65	0.00	0.00
	16	42.1	42.1059	0.0059	0.00003481	41.75	-0.35	0.1225
	16	47.8	47.74191	0.00581	0.00003374	47.81	0.01	0.0001
	20	44.7	44.70734	0.00734	0.00005388	44.71	0.01	0.0001
	20	50.03	50.03734	0.00734	0.00005388	50.04	0.01	0.0001
	20	47.9	47.90731	0.00731	0.00005084	47.91	0.01	0.0001
	25	51.55	51.55913	0.00913	0.00008336	51.56	0.01	0.0001
	25	51.03	50.07469	-0.95531	0.9126172	50.08	-0.95	0.9025
	25	51.24	51.24913	0.00913	0.00008336	51.25	0.01	0.0001
NUM TOTAL		585.22	584.272	-0.94834	0.91311023	584.01	-1.21	1.0259

**Table 5.9: Tensile Strength at Maximum Load without Iron (Experimental
Data, Numerical Data and Computer Software Result) of Rolled
Ribbed Medium Carbon Steel**

No.	Dia. (mm)	EXP VALUE	NUM VALUE 1	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)	SOFT WARE VALUE 2	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)
	12	602.84	602.8356	-0.0044	0.00001936	602.84	0.00	0.00
	12	673.18	673.1763	-0.0037	0.00001369	673.13	-0.05	0.0025
	12	637.875	637.8711	-0.0039	0.00001521	637.87	-0.01	0.0001
	16	590.16	590.1539	-0.0061	0.00003721	590.15	-0.01	0.0001
	16	567.26	567.254	-0.006	0.000036	567.25	-0.01	0.0001
	16	578.71	578.7041	-0.0059	0.00003481	578.70	-0.01	0.0001
	20	638.06	638.0536	-0.0064	0.00004096	638.05	-0.01	0.0001
	20	644.67	644.6638	-0.0062	0.00003844	644.66	-0.01	0.0001
	20	641.365	641.3584	-0.0066	0.00004356	641.36	-0.01	0.0001
	25	772.72	772.7118	-0.0082	0.00006724	772.71	-0.01	0.0001
	25	673.87	668.1728	-5.6972	32.4580878	668.17	-5.7	32.49
	25	723.295	723.287	-0.008	0.000064	723.28	-0.01	0.0001
NUM TOTAL		7744.005	7738.242	-5.7626	32.4584983	7738.17	-5.62	32.4934

Table 5.10: Tensile Strength at Break without Iron (Experimental Data, Numerical Data and Computer Software Result) of Rolled Ribbed Medium Carbon Steel

S/No.	Dia. (mm)	EXP VALUE	NUM VALUE 1	PAIR DIFF (d)	SQUARE OF PAIR DIFF. (d ²)	SOFT WARE VALUE 2	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)
A	12	469.84	469.8385	-0.0015	0.00000225	469.84	0.00	0.00
B	12	494.83	494.828	-0.002	0.000004	494.83	0.00	0.00
C	12	482.335	482.3332	-0.0018	0.00000324	482.33	0.005	0.000025
D	16	473.55	473.547	-0.003	0.000009	473.55	0.00	0.00
E	16	448.99	448.987	-0.003	0.000009	448.99	0.00	0.00
F	16	461.27	461.2666	-0.0034	0.00001156	461.27	0.00	0.00
G	20	551.84	551.8363	-0.0037	0.00001369	551.84	0.00	0.00
H	20	579.78	579.7763	-0.0037	0.00001369	579.78	0.00	0.00
I	20	565.81	565.8064	-0.0036	0.00001296	565.81	0.00	0.00
J	25	671.14	671.1351	-0.0049	0.00002401	671.14	0.00	0.00
K	25	611.87	606.9917	-4.8783	23.7879109	606.99	-4.88	23.8144
L	25	641.505	641.5003	-0.0047	0.00002209	641.50	0.005	0.000025
SUM TOTAL		6452.78	6447.846	-4.9136	23.7880365	6447.87	-4.89	23.8145

Table 5.11: Yield Strength without Iron (Experimental Data, Numerical Data and Computer Software Result) of Rolled Ribbed Medium Carbon Steel

S/No.	Dia. (mm)	EXP VALUE	NUM VALUE 1	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)	SOFT WARE VALUE 2	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)
A	12	452.713	452.7183	0.0053	0.00002809	452.71	-0.003	0.000009
B	12	486.313	486.3182	0.0052	0.00002704	486.32	-0.007	0.000049
C	12	469.512	469.5172	0.0052	0.00002704	469.52	0.008	0.000064
D	16	445.639	445.647	0.008	0.000064	445.65	0.011	0.000121
E	16	406.734	406.7419	0.0079	0.00006241	406.74	0.006	0.000036
F	16	426.187	426.195	0.008	0.000064	426.14	-0.027	0.000729
G	20	406.734	406.7432	0.0092	0.00008464	406.74	0.006	0.000036
H	20	424.418	424.4271	0.0091	0.00008281	424.43	0.012	0.000144
I	20	415.576	415.5853	0.0093	0.00008649	415.59	0.014	0.000196
J	25	459.186	459.1978	0.0118	0.0001392	459.20	0.014	0.000196
K	25	397.892	391.8723	-0.0197	0.00038809	391.87	-6.022	36.2645
L	25	428.839	428.8507	0.0117	0.00013689	428.85	0.011	0.000121
SUM TOTAL		5219.743	5213.813	0.071	0.00119154	5213.78	-5.977	36.2662

Table 5.12: Impact Strength without Iron (Experimental Data, Numerical Data and Computer Software Result) of Rolled Ribbed Medium Carbon Steel

S/N	Dia. (mm)	EXP VALUE	NUM VALUE 1	PAIR DIFF (d)	SQUARE OF PAIR DIFF. (d ²)	SOFT WARE VALUE 2	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)
A	12	84	83.9976	-0.002	0.000004	83.40	-0.6	0.36
B	12	100	99.99754	-0.002	0.000004	99.40	-0.6	0.36
C	12	100	99.99758	-0.002	0.000004	99.40	-0.6	0.36
D	16	65	64.99651	-0.003	0.000009	64.40	-0.6	0.36
E	16	52	51.9965	-0.003	0.000009	51.40	-0.6	0.36
F	16	52	51.99651	-0.003	0.000009	51.40	-0.6	0.36
G	20	50	49.99557	-0.004	0.000016	49.40	-0.6	0.36
H	20	45	44.99558	-0.004	0.000016	44.40	-0.6	0.36
I	20	48	47.99556	-0.004	0.000016	47.40	-0.6	0.36
J	25	30	29.99443	-0.006	0.000036	29.40	-0.6	0.36
K	25	42	40.57689	-1.423	2.024929	39.98	-2.02	4.0804
L	25	32	31.99443	-0.006	0.000036	31.40	-0.6	0.36
SUM TOTAL		700	698.538	-1.462	2.025088	691.38	-8.62	8.0404



Plate 1: Microstructure of 25mm Diameter of Rolled Ribbed Medium Carbon Steel. (x400) (un-etched)



Plate 2: Microstructure OF 25mm Diameter of Rolled Ribbed Medium Carbon Steel. (x400) (etched)



Plate 3: Microstructure of 25mm Diameter of Rolled Ribbed Medium Carbon Steel. (x800) (etched)

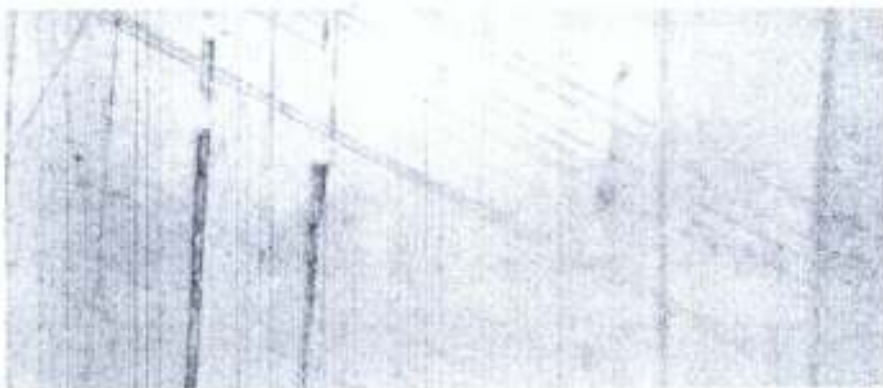


Plate 4: Microstructure of 20mm Diameter of Rolled Ribbed Medium Carbon Steel. (x400) (un-etched)



Plate 5: Microstructure of 20mm Diameter of Rolled Ribbed Medium Carbon Steel. (x400) (etched)



Plate 6: Microstructure of 20mm Diameter of Rolled Ribbed Medium Carbon Steel. (x800) (etched)



Plate 7: Microstructure of 16mm Diameter OF Rolled Ribbed Medium Carbon Steel. (x400) (un-etched)



Plate 8: Microstructure of 16mm Diameter of Rolled Ribbed Medium Carbon Steel. (x400) (etched)



Plate 9: Microstructure of 16mm Diameter of Rolled Ribbed Medium Carbon Steel. (x800) (etched)



Plate 10: Microstructure of 12mm Diameter of Rolled Ribbed Medium Carbon Steel. (x400) (un-etched)



Plate 11: Microstructure of 12mm Diameter of Rolled Ribbed Medium Carbon Steel. (x400) (etched)

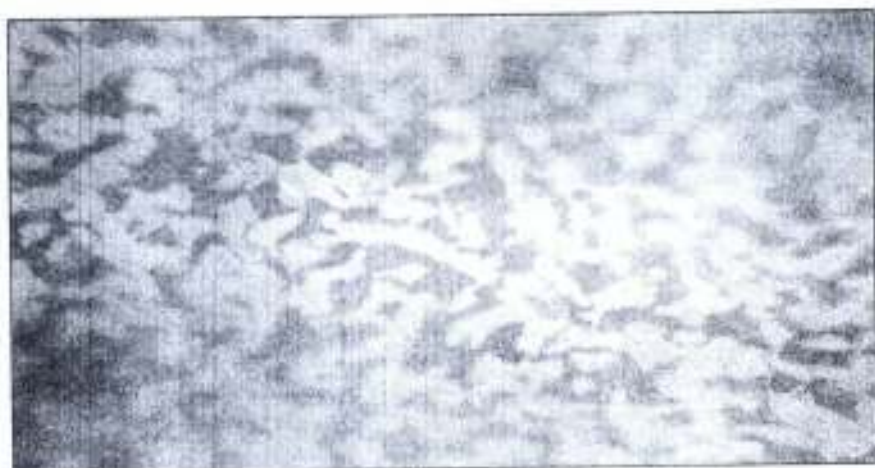


Plate 12: Microstructure of 12mm Diameter of Rolled Ribbed Medium Carbon Steel. (x800) (etched)

5.2 DISCUSSION OF RESULTS

5.2.1 EFFECT OF DEPENDENT VARIABLES ON THE MECHANICAL PROPERTIES

5.2.1.1 Effect of Sample Sizes on Mechanical Properties

The mechanical properties of plain carbon steel are usually dictated by the combined effect of composition and grain size. It is often difficult to quantify the individual contributions to the strength. Critical observation of all the Plates 1 - 12 revealed that the samples micro-structures consist of proeutectoid ferrite and pearlite, with Plates 2 and 3 having largest proportion of pearlite. The pearlite is the grey colour while the ferrite appeared as white. As shown in Figures 5.1 to 5.6, the 12mm diameter rolled ribbed rod showed a better strength than that of 16mm diameter rod despite having very close carbon content. This may have been as a result of the extent of its grain size refinement effect. Here in 12mm diameter rod, due to its smaller size, it will experience a faster rate of cooling which is dependent on dimension, therefore, brought about a finer grain size as against 16mm diameter rod that will take slower cooling rate. Therefore, there will be tendency for grain growth in 16mm rod more than 12mm diameter rod will experience. This also accounted for the relatively higher yield strength and tensile strength for 12mm rod than 16mm rod. The Hardness values, both transverse and longitudinal were also higher for 12mm rod than 16mm rod. This observation is in agreement with the scientific analysis of the relationship between grain size and strength of Hall-Petch and the theory of yield point which involve the breaking away of dislocation from interstitial carbon atmosphere. The grain size effect on yield strength can therefore be explained by assuming that a dislocation source operates within a crystal causing dislocations to move and eventually pile up at the grain boundary. The grain size therefore determines the

distance dislocations have to move and the number of grain boundary it has to cross in order to propagate. This implies that the bigger the grain size, the easier it will be to propagate the yielding process. It therefore holds practically that the finer the grain size, the higher the resulting strength. (Honeycombe and Bhadeshia, 1995).

However, in the case of 20mm and 25mm diameter rods, the 25mm rod displayed higher strength than did 20mm rod. And this may have been due to the effect of composition. The 25mm rod contains higher content of carbon and even manganese than 20mm rod. These two elements are strengtheners. Though, the cooling effect ought to have favoured 20mm rod to have higher strength value, but the composition had a dominant effect on it. These also account for the highest value recorded for the hardness values of 25mm rod. But for the hardness values and strength of 20mm rod, there seems to be a presence of flaws like blow holes in the material which may have accounted for the drop in the hardness values and the strengths.

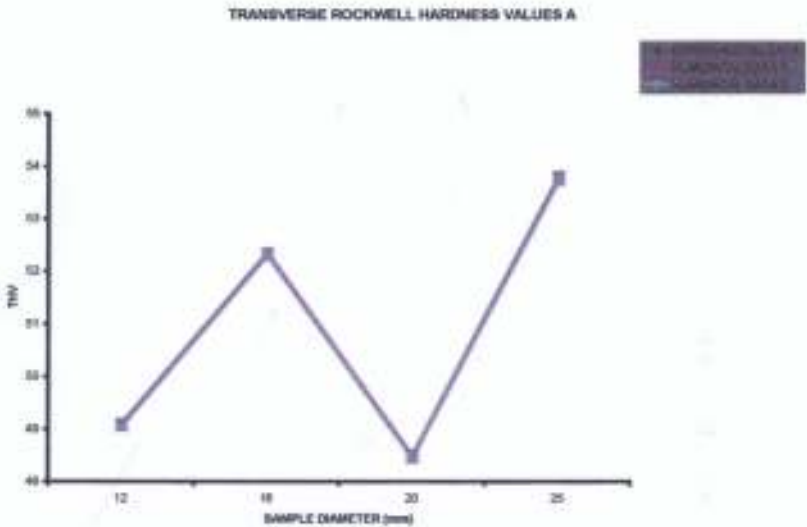


Figure 5.1: The Variation of Transverse Rockwell Hardness Values A with Samples Sizes of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.

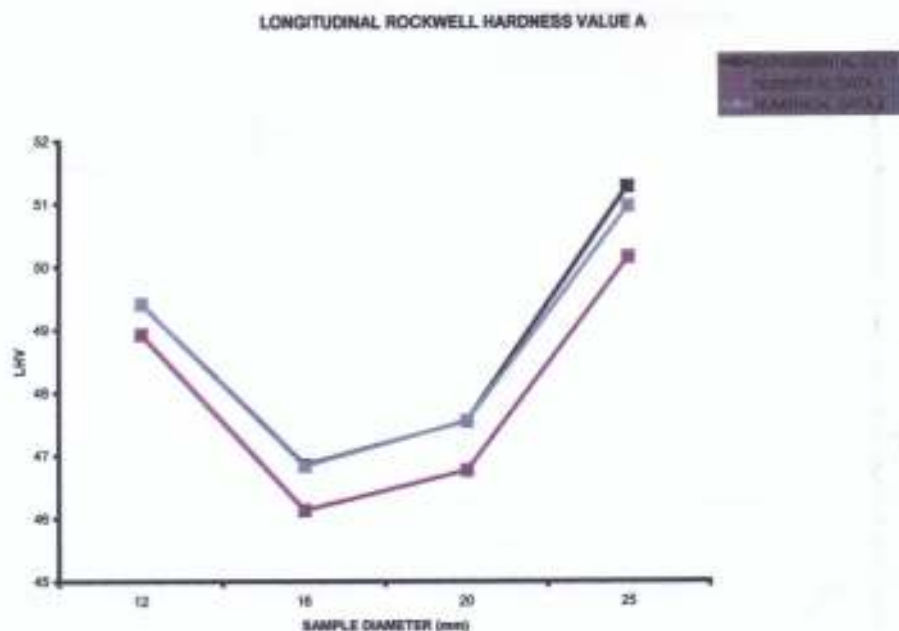


Figure 5.2: The Variation of Longitudinal Rockwell Hardness Values A with Samples Sizes of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.

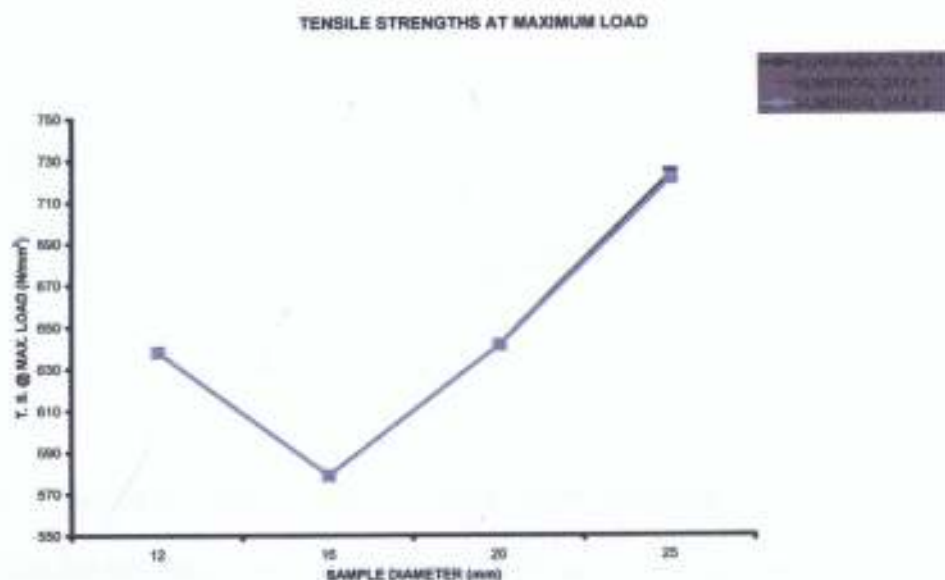


Figure 5.3: The Variation of Tensile Strength at maximum load (N/mm²) with Samples Sizes of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.

TENSILE STRENGTHS AT BREAK

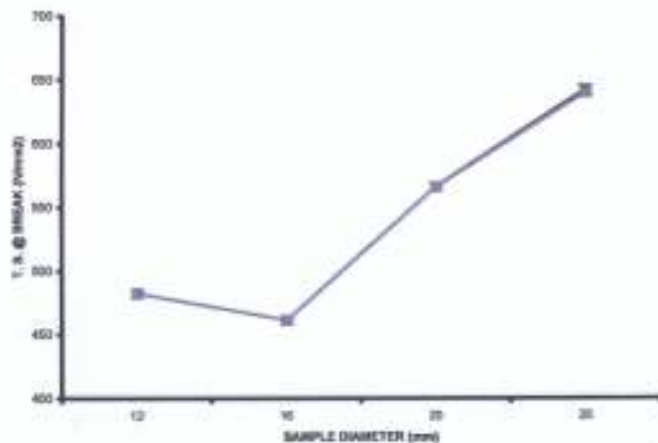


Figure 5.4: The Variation of Tensile Strength at Break (N/mm^2) with Samples Sizes of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.

YIELD STRENGTHS

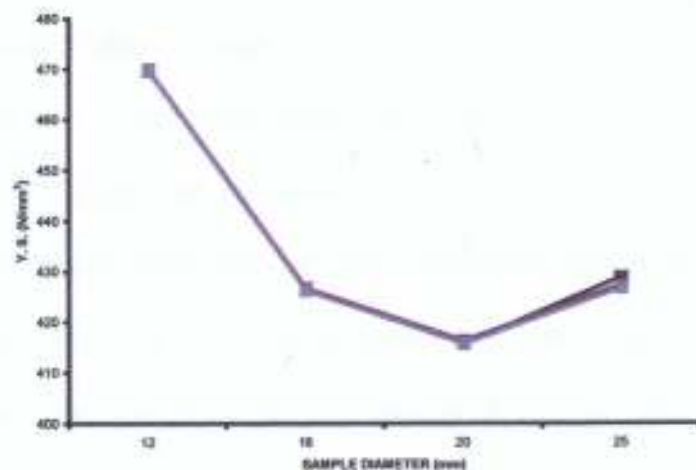


Figure 5.5: The Variation of Yield Strength (N/mm^2) with Samples Sizes of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.

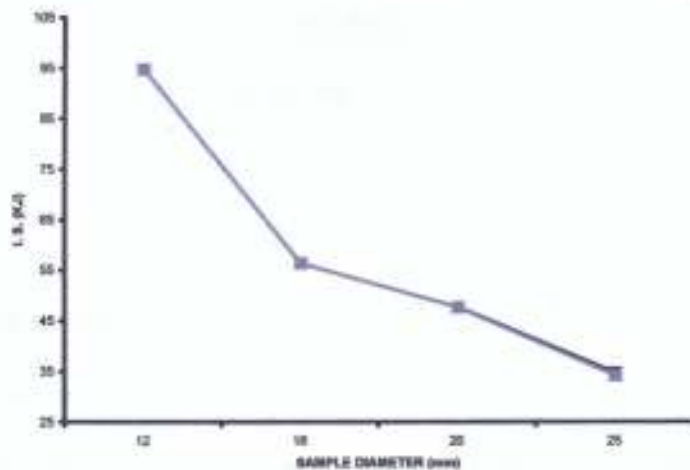


Figure 5.6: The Variation of Impact Strength (KJ) with Samples Sizes of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.

5.2.1.2 Effects of Chemical Composition on Mechanical Properties

Plates 2, 3, 5, 6, 8, 9, 11 and 12 show that the materials consist of pro-eutectoid ferrite and pearlite with 25mm rod containing more proportion of pearlite than others, followed by 20mm rod, 16mm rod and lastly 12mm rod. This confirms that they were all subjected to a relatively slow cooling regime to avoid the formation of metastable phases. The morphology however was governed by the rate of cooling, i. e. normalizing.

These structures were obtained because the materials were primarily plain carbon steels (medium carbon steels) and the other alloying elements were only in traces made for steel making purposes. Though, they may still play minute strengthening role as well. The plain carbon steels essentially are materials which depend for their mechanical properties on carbon content (0.05% – 1%) and manganese (0.25% -

1.7%) and particularly medium carbon steels contain carbon content of 0.3% - 0.6%. Therefore, the concentrations of these two elements in 12mm and 16mm rods were observed to have been responsible for the higher strength of 12mm rod than 16mm rod as displayed in Figures 5.7 to 5.12. The same trend occurred in the tensile and yield strengths. Observations of Plates 2 and 3 showed that 25mm rod contains highest portions of pearlite, and pearlite provide substantial contributions to strength i.e. tensile and yield strength. This was due to the fact that there is a linear relationship between work hardening rate and pearlite content which arises because pearlite work hardens much more rapidly than ferrite. All these accounted for the higher strength of 25mm rod than 20mm rod which has relatively closer chemical composition. The hardness values were also of the highest due to the combination of the composition of the two elements. The drop in the hardness values of 20mm rod when compared to those of 16mm rod despite higher carbon and manganese contents may have been due to flaws in the materials.

However, the case of impact strength was quite different as shown in Figures 5.6 and 5.12 as the lowest values were recorded for the 25mm rod despite having highest values in the other properties estimated. This may have been as a result of its largest proportion of pearlite which has been known to have adverse effect on toughness and ductility of plain carbon steels. The higher the pearlite content, the more the impact transition temperature is raised and the less the impact energy absorbed. This is due to the fact that the presence of pearlite in the micro-structure provides sites for easy nucleation of cracks, particularly at the ferrite-cementite interfaces. But, a crack can only propagate a short distance in ferrite before encountering another cementite-lamella. Energy is absorbed during the propagation. The result is that there is a wide transition temperature. This implies that the low energy absorbed in the overall impact

tests on the more pearlite structures arises from the fact that many nuclei would have occurred at the pearlitic interface which, together with the high work hardening rate, restricts plastic deformation in the vicinity of the crack. (Honeycombe and Bhadeshia, 1995).

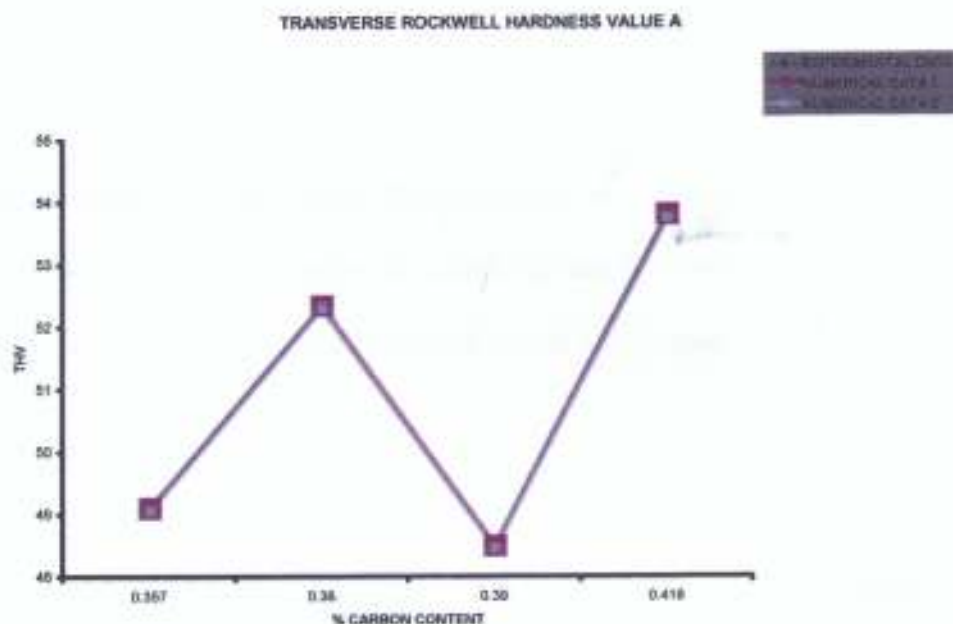


Figure 5.7: The Variation of Transverse Rockwell Hardness Values A with %Carbon Content of Samples of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.

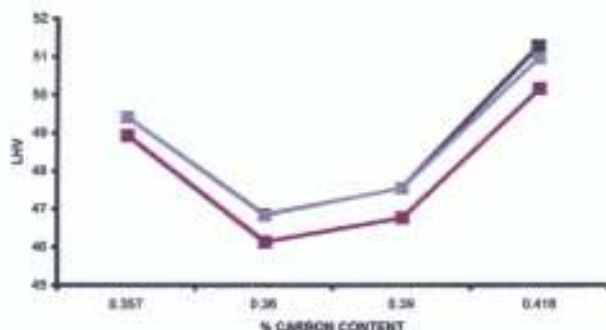


Figure 5.8: The Variation of Longitudinal Rockwell Hardness Values A with %Carbon Content of Samples of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.

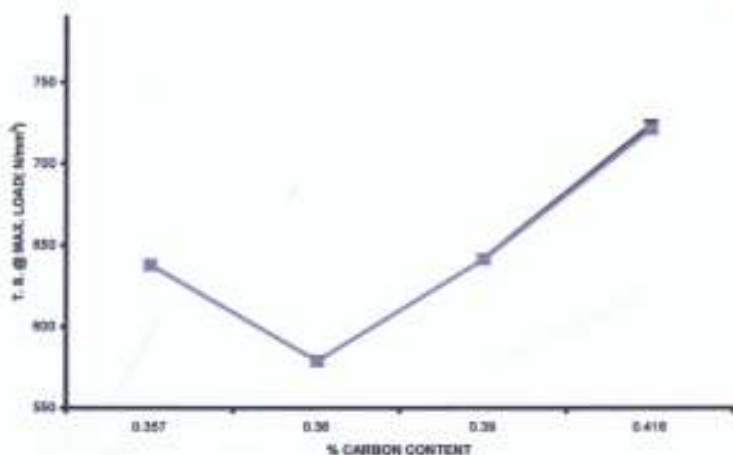


Figure 5.9: The Variation of Tensile Strength at maximum load (N/mm^2) with %Carbon Content of Samples of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.

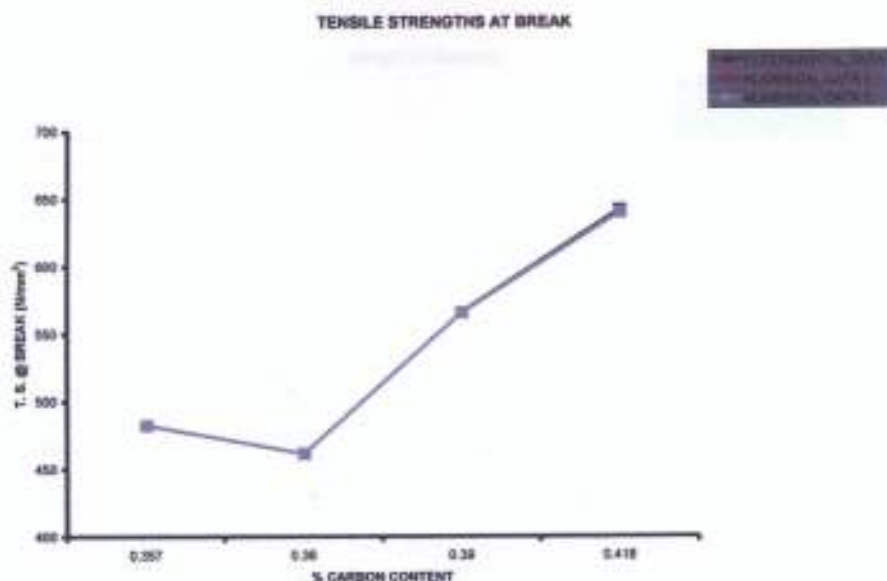


Figure 5.10: The Variation of Tensile Strength at Break (N/mm^2) with %Carbon Content of Samples of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.

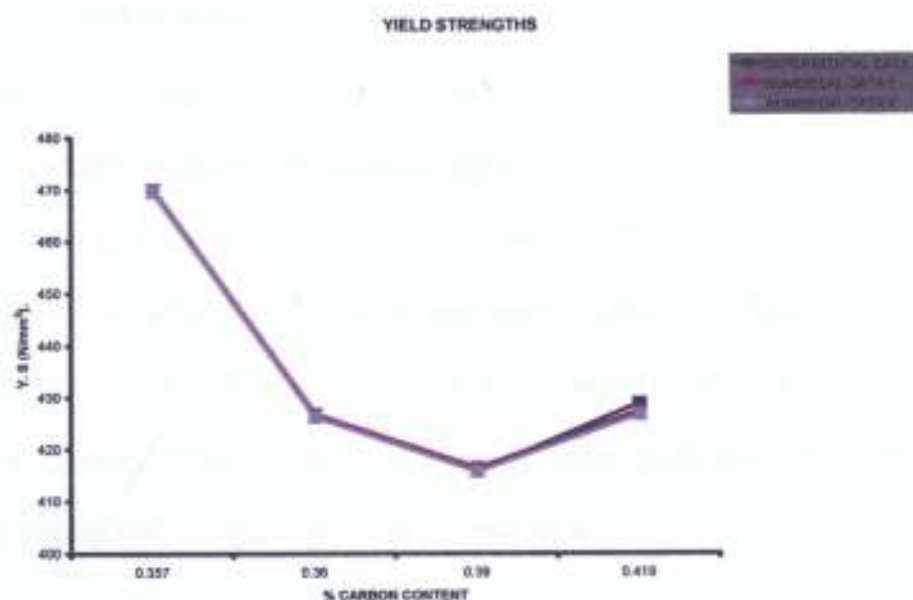


Figure 5.11: The Variation of Yield Strength (N/mm^2) with %Carbon Content of Samples of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.

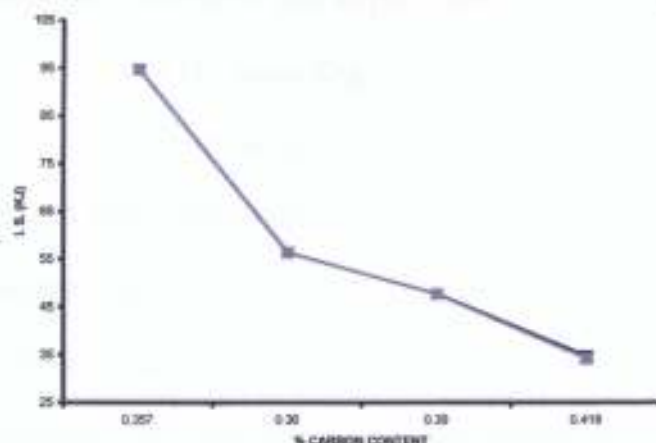


Figure 5.12: The Variation of Impact Strength (KJ) with %Carbon Content of Samples of Rolled Ribbed Medium Carbon Steel Rods for both Experimental and Numerical Values.

5.2.3 Models with and without Iron

A critical observation of both types-models developed was made. This revealed that the type-2, i. e. models without iron inclusive predicted the observed value more accurately than the type-1 (models with iron inclusive). This could be seen as calculated and shown in Tables 5.1 – 5.6 in comparison to Tables 5.7 – 5.12. Though, both models types are valid, but type-2 predicted almost exactly the same values of the experimental values. Hence, type-2 models are more preferred for perfect accuracy and reliability with insignificant error of prediction.

5.2.4 Validation of the Results

As showed in Figures 5.1 to 5.12, the experimental data plotted against the numerical data indicated that the numerical and experimental values were much correlated. This

means that there was good agreement between the two values. The paired t-tests that were used to validate the models also confirmed that there was no significant difference between the numerical and experimental values. This was summarily described in Tables 4.2 to 4.13. According to Aderoba, (1995), a very high positive correlation (R) was observed when the coefficient of correlation test was carried out on the numerical and experimental data of all the mechanical properties estimated. This is an indication of excellent reliability of the obtained data.

There was none of the data that contain more than 2.721 % when the standard error test was done on both the numerical and experimental data. This implies good agreement in the two data as the standard error obtained can be considered insignificant and therefore neglected. Tables 4.8 to 4.13 showed the values.

Since according to all the tests carried out, there was good agreement between the numerical and experimental data, it can therefore be said that the developed models were reliable and valid. And they can be used to estimate the mechanical properties of rolled ribbed medium carbon steels that were studied

5.2.5 Limitation of the Models

- a) The application of these models are limited to the estimation of mechanical properties of rolled ribbed medium carbon steels only for which the modelling was based for accuracy of prediction
- b) The models may not be suitable for the estimation of mechanical properties of plain bars even of the same compositions and sizes
- c) The application of the models are subject to the fulfilment of the assumptions of the models for the sake of accuracy

- d) It is not suitable for cast, extruded or forged steel even of the same compositions and sizes

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSIONS

The following conclusions were drawn from the research work:

1. The multiple regression analysis is a powerful tool to estimate theoretically the mechanical properties of rolled ribbed medium carbon steel rods.
2. The numerical and experimental values were in agreement with each other.
3. The models developed are excellent in predicting the mechanical properties of the materials studied.
4. The models type-II is more accurate than the models type-I in predicting the mechanical properties.
5. The percentage carbon content has great influence in determining the mechanical properties of the materials as they all increased with increase in carbon content except impact strength which decreased with increase in carbon content.
6. The dimensions of the rods also have effect on the mechanical properties of the materials.
7. The software developed is excellent in rapidly predicting the mechanical properties of the materials studied.
8. Based on the results obtained and afore-mentioned facts, I therefore conclude that there is need for modelling the mechanical properties of rolled ribbed medium carbon steel rods since the experimental determination of these properties could not be properly achieved by the Rolling Mills as a result of

high cost of equipment, variations in data as well as energy problem among others. The software developed can therefore solve the problems.

6.2 RECOMMENDATIONS

Based on the conclusions made above, I recommends that the developed software "ROLLED STEEL INFORMATION SYSTEM 2010" that was developed from the models be used by the Rolling Mills, Research Institutes, Civil/Structural Engineers as well as Regulatory agencies to estimate the mechanical properties of rolled products; particularly, rolled ribbed medium carbon steel rods.

6.3 SUGGESTIONS FOR FURTHER WORK

I wish to suggest that investigations be conducted on the estimation of mechanical properties of rolled ribbed low carbon steels, rolled plain medium carbon steels and rolled plain low carbon steels all produced in Nigerian Rolling Mills. These will help to provide adequate information on the materials for the construction industries.

REFERENCES

- Aderoba, A. (1995).** Tools of Engineering Management: Engineering Management Project. Besade Publishers Nigeria Limited, Akure-Nigeria. Pp 19 – 21.
- Anderson, David, R.; Sweeney Dennis J. And Williams Thomas A. (1981)** Introduction to Statistics: An applicationa Approach. West Publishing Company. USA Pp 369 – 372.
- Azeez, O. I.; Raji, S. T.; Okeniyi, O. M. and Adepoju, J. A. (2nd ed. 2004)** An Introduction to Business Statistics and its Application. Rajah Dynamic Printers, Ilorin Nigeria. Pp 90 – 98.
- Burtsev, k. (1973).** Rolling Practice MIR Publishers, Moscow. Pp 84 – 85.
- Cao, G. M.; Li, G. C.; Liu, Z. Y.; Wang, D. G. and Liu, X. H. (2008).** Numerical Simulation of Molten Pool and Control Strategy of Kiss Point in a Twin-Roll Strip Casting Process. ACTA Metallurgical Sinica (English letter), Vol. 21, No. 6. Pp 459 – 468.
- Chopra, O. K. (1994).** Estimation of Fracture Toughness of Cast Stainless Steels during Thermal Aging in LWR systems. NUREG/CR-4513, Rev. 1 AIL-93/22.
- Cross, M. and Moscardiac, A. O. (1985)** Learning the Art of Mathematical Modelling. Ellis Horivood Limited, Chichester. England. P56.
- Daniel, A. Brand (1985)** Metallurgy Fundamentals. The Goodherat – Willcox Company Inc. Publishers. P 113.
- Dass, H. K. (2005).** Advance Engineering Mathematics. S. Chand & Company Limited. New Delhi. Pp 675 – 689.
- Dilwyn Edwards and Mike Hamson (1993 Reprinted)** Guide to Mathematical modelling. The Macmillan Press Limited, Hong Kong. Pp 1 – 46.
- Donald, S. Clark and Wilbur, R. Varney (1987)** Physical Metallurgy for Engineers.

Dumortier, L. and Leher, P. (1999). Statistical Modelling of Mechanical Tensile Properties of Steels by using Neural Networks and Multivariate Data Analysis, ISIJ International, Vol. 39, No. 10. Pp 980 – 985.

George, E. Dieter (1988) Mechanical Metallurgy. McGraw-Hill Book Company, Singapore. Pp 278 – 283.

Honeycombe, R. W. K. And Bhadeshia H. K. D. H. (1995). Steels: Microstructure and Properties. Edward Arnold publishers, London. Pp 24 – 58.

Hua DING; Zheng-You TANK; Wei LI; Mei WANG and Don SONG. (2006). Microstructures and Mechanical Properties of Fe-Mn-(Al, Si) TRIP/TWIP steels. Journal of Iron and Steel Research, International. Vol. 13 issue No. 6 Inc. Pp 112 - 114.

Javoronko, V. A. And Chaturvedi, R. C. (1981) Rolling of Metals. Yantrik Publisher, Bombay. Pp 16 – 115.

Jin Seol, D.; Hwan Oh, K.; Wook Cho, J.; Lee, J. -E. and Yoon, U. -S. (2002). Phase- Field Modelling of the Thermo-Mechanical Properties of Carbon Steels. ACTA Materialia, Vol. 50, No. 9. Pp 2259 – 2268.

Kenneth, G. B. (1979). Engineering Materials, Properties and Selection. Reston Publishing Company Inc. Reston, Virginia. Pp 1 – 15.

Khurmi, R. S. (1992) Strength of Materials. S. Chand & Company Limited Ramnagar, New Delhi. India. Pp 975 – 976.

Lakhtin, Yu. M. (1979) Engineering Physical Metallurgy and Heat Treatment. Mir Publishers, Moscow. Translated from Russia into English by Nicholas Weinstein. Pp 287 – 293.

Lalam, S. H.; Bhadeshia, H. K. D. H. and Mackay, D. J. C. (2000). Estimation of Mechanical Properties of Ferritic Steel Welds- Yield and Tensile strenghts.

Science and Technology of Welding and Joining, Vol. 5, No. 3 Pp 149 – 160.

Lalam, S. H.; Bhadeshia, H. K. D. H. and Mackay, D. J. C. (2000). Estimation of Mechanical Properties of Ferritic Steel Welds- Elongation and Charpy-Impact Toughness. Science and Technology of Welding and Joining, Vol. 5, No. 3 Pp 135 – 147.

Liu, D. R.; Guo, E. J. and Wang, L. P. (2008). Modelling of ‘Banding’ Microstructure Formulation in Centrifugally Solidified Ti-6Al-4V alloy. ACTA Metallurgical inica (English letter), Vol. 21, No. 6. Pp 399 – 408.

Llewellyn, D. T. (1992). Steels: Metallurgy and Applications: Butterworth-Heinemann Ltd, Oxford. Pp 102 – 108.

Martyn, S. R. (1949). The Technology and Applications of Engineering Materials: Prentice Hall International Ltd, UK. P 393.

Mendenhall, William; Scheaffer, L. Richard and Wackerly, D. Dennis (1981) Mathematical Statistics with Applications, Duxbury Press USA. Pp424 – 433.

Myllykoski, P.; Larkiola, J. and Nylander, J. (1996). Development of Prediction Model for Mechanical Properties of Batch Annealed Thin Steel Strip by using Artificial Neural Network Modelling. Journal of Materials Process Technology. Vol. 60, No. 1-4. Pp 399 – 404.

Ndaliman, M. B. (2006). An Assesment of Mechanical Properties of Medium Carbon Steel under different Quenching Media using AISI Steel Grade of C1035. AU: Journal of Technology; 10(2), Pp 100 – 104.

Neil, J. and Ravindra, K. D. (1996). Civil Engineering Materials: Macmillan Press Ltd, Hong Kong. P 187.

Oyetunji, A. (2007) Modelling Mechanical Properties of Grey Cast Iron. Ph D Thesis submitted to the Department of Metallurgical and Materials Engineering, Federal University of Technology, Akure-Nigeria.

Oyetunji, A. and Adebisi, J.A. (2009). Development of Software for Rapid Estimation of Corrosion Rate of Austempered Ductile Iron in corrosive media. **Australian Journal of Basic and Applied Sciences**, INSINET Publication, Pakistan. Vol. 3(3). Pp 2801 – 2808.

Oyetunji, A. (2010). “Modelling the Impact Properties of Grey Cast Iron Produced from CO₂ and Steel Moulds” **Journal of Applied Science Research**, ISINET Publication Pakistan. Vol. 6(5), Pp 393 – 400.

Pascoe, K. J. (1978). An Introduction to Properties of Engineering Materials. ELBS London. P 187.

Rajan, T. V., Sharma, C. P. and Sharma Ashok (1988) Heat Treatment, Principles and Techniques. Prentice-hall of India private limited. New Delhi -110001. Pp 51 – 53.

Sherif, D. Wakil (1994) Materials Science and Engineering Lab Manual. PWS Publishing Company, Boston. P 17.

Simecek, P. and Hajduk, D. (2007). Prediction of Mechanical Properties of Hot Rolled Steel Products. Journal of Achievement in Materials and Manufacturing Engineering. Vol. 20, Issues 1-2. Pp 395 – 398.

Sterjovski, Z.; Nolan, D.; Carpenter, K. R.; Dunne, O. P. and Norrish, J. (2005). Artificial Neural Networks for Modelling the Mechanical Properties of Steels in Various Applications. Journal of Materials Processing Technology. Vol. 170, No. 3 Pp 536 – 544.

Vernon, L. S. (1977). Manufacturing Materials. Charles E. Merrill Publishing Company. A bell and Howell Company Columbus. Pp 1 – 44.

Wilfrid, J. Dixon and Massey, Frank J. (1969) Introduction to Statistical analysis. McGraw-Hill Book Company, USA. Pp193 – 215.

Williams, D. C. (2000). Materials Science and Engineering An Introduction: John Wiley & Sons, New York, USA. Pp 113 – 353.

William, F. Smith (1990) Principle of Materials Science and engineering. Migraw-Hill Publishing Company, New York. Pp 262 – 271.



STATISTICAL TESTS USED FOR THE VALIDATION OF DEVELOPED
MODELS THAT ESTIMATE THE MECHANICAL PROPERTIES OF THE
ROLLED RIBBED MEDIUM CARBON STEELS

A: PAIR T-TESTS

Table 5.1: Transverse Hardness Value with Iron (Experimental and Numerical Data) of Rolled Ribbed Medium Carbon Steel

S/N	Dia. (mm)	EXP VALUE	NUM VALUE 1	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)	SOFT WARE VALUE 1	PAIR DIFF. (d)	SQUARE OF PAIR DIFF. (d ²)
A	12	49.6	49.64368	0.04368	0.00219	49.64	0.04	0.0016
B	12	48.57	48.6138	0.0438	0.00192	48.61	0.04	0.0016
C	12	48.98	49.02357	0.04357	0.00190	49.92	0.04	0.0016
D	16	52.25	52.29407	0.04407	0.00194	52.26	0.01	0.001
E	16	52.33	52.37405	0.04405	0.00194	52.34	0.01	0.001
F	16	52.3	52.344	0.044	0.00194	52.34	0.04	0.0016
G	20	47.45	47.49427	0.04427	0.00196	47.49	0.04	0.0016
H	20	49.93	49.97425	0.04425	0.00196	50.07	0.14	0.28
I	20	47.94	47.98426	0.04426	0.00196	47.98	0.04	0.0016
J	25	54.05	54.09428	0.04428	0.00196	54.09	0.04	0.0016
K	25	53.5	53.52508	0.02508	0.00063	53.52	0.02	0.0004
L	25	53.72	53.76426	0.04426	0.00196	53.76	0.04	0.0016
SUM TOTAL		610.63	611.129	0.50957	0.02225	611.12	0.5	0.2934

(a) Mean of Pair difference ($\bar{d}$)

$$(\bar{d}) = \frac{\sum (\text{Numerical data} - \text{Experimental data})}{\text{No of paired test samples}}$$

$$\bar{d} = \frac{0.50957}{12} = 0.042464766$$

(b) Variance of Pair difference Var (d)

$$\text{Var (d)} = \frac{\sum d^2 - \frac{(\text{Numerical data} - \text{Experimental data})^2}{\text{No.of Paired test samples}}}{\text{No of paired test samples} - 1}$$

$$\text{Var(d)} = \frac{0.0222511 - \frac{(0.50957)^2}{12}}{12 - 1} = 0.00005569$$

(c) Variance of mean of Pair difference Var ($\bar{d}$)

$$\text{Var}(\bar{d}) = \frac{\text{Var}(d)}{\text{No of paired test samples}}$$

$$\text{Var}(\bar{d}) = \frac{0.00005569}{12} = 0.000004641 = 4.641 \times 10^{-6}$$

(d) Standard deviation of Mean of pair difference (Sd)

$$\text{Sd} = \sqrt{\text{Var}(\bar{d})}$$

$$\text{Sd} = \sqrt{\text{Var}(\bar{d})} = \sqrt{4.641 \times 10^{-6}} = 0.0021543$$

(e) Acceptable tolerance interval for a given confidence interval and numerical data

$$\text{THV}_t = \bar{d} \pm t_{v(1-\alpha)} \text{Sd}$$

Where:

t_v = Degree of freedom available for a given confidence interval (α)

V = Number of degree of freedom

N = Number of pair test samples

α = Confidence interval (%)

Sd = Standard deviation

Using confidence interval 99.9%; $\alpha = 0.999$, therefore $1-\alpha = 1- .0999 = 0.001$

$N = 12$, $V = N -1 = 12-1 = 11$

Therefore, $t_{v(1-\alpha)} = t_{v(0.001)}$

And from the percentage points of the t-distribution,

$t_{v(0.001)} = 4.44$ (obtained from percentage points of the t-distribution table in

appendix...)

$\bar{d} = 0.0425$ and

$Sd = 0.0021543$

Therefore, by substitution these values in equation....

We have:

$$0.0425 \pm 4.44 (0.0021543)$$

$$= 0.0329 \text{ to } 0.05207$$

Therefore, the interval extends from 0.0329 to 0.05207

It could be observed that the interval tolerance range obtained for 99.9% confidence interval was very narrow.

B: CORRELATION COEFFICIENT

The correlation coefficient equation used is as shown below

$$\text{Coefficient correlation } R = \sqrt{1 - \frac{\sum (Y_a - Y_c)^2}{\sum (Y_a - \bar{Y})^2}} = \sqrt{1 - \frac{\sum d^2}{\sum (x - \bar{x})^2}}$$

Where:

Y_c = Predicted value

Y_a = Experimental value

$\bar{Y}$ = Average of Y_a and

$\bar{Y}$ = Average of Y_s

$$R = \sqrt{1 - \frac{\sum d^2}{\sum (x - \bar{x})^2}} = \sqrt{1 - \frac{0.0222511}{62.869912}}$$
$$= \sqrt{0.9997} = 0.9998$$

C: STANDARD ERROR OF PREDICTION

The equation for calculating the standard error of the predicted numerical data (Y) is given as:

$$E_{y-x} = \sqrt{\frac{\sum (Y - Y_r)^2}{N}}$$

Where:

Y = the Actual value (experimental value)

Y_r = the Predicted value (Numerical value)

$$SE = \sqrt{\frac{\sum (Y - Y_r)^2}{N}} = \sqrt{\frac{\sum d^2}{N}}$$
$$= \sqrt{\frac{0.0222511}{12}} = \sqrt{0.001854258}$$
$$= 0.043$$

“SOFTWARE NAMED ROLLED STEEL INFORMATION SYSTEM 2010”

ROLLED STEEL INFORMATION SYSTEM 2010 WAS DEVELOPED FOR RAPID ESTIMATION OF MECHANICAL PROPERTIES OF ROLLED RIBBED MEDIUM CARBON STEEL RODS.

ROLLED STEEL INFORMATION SYSTEM 2010 COMPUTER SOFTWARE WILL BE USEFUL TO SOME OF THE FOLLOWING SECTORS:

- (1) Indigenous Rolling Mills to estimate the mechanical properties of their products at ease.
- (2) The users (Civil and Structural Engineers) of the products can also confirm the properties to avoid design error before use.
- (3) The government agency like Standard Organisation of Nigeria (SON) can make use of the software developed in ensuring compliance of products to specifications.
- (4) It will be of advantage to the research institutes that use rolled ribbed medium carbon steel.

COMPUTER ALGORITHM FOR THE DEVELOPED ROLLED STEEL INFORMATION SYSTEM 2010

```

Private Sub cmdClear_Click()
txtManganese.Text = ""
txtCarbon.Text = ""
txtMaterialType.Text = ""
End Sub

Private Sub cmdMaterialType_Click()
Dim Carbon, Manganese As Single
Dim MaterialType As String
Carbon = Val(txtCarbon.Text)
Manganese = Val(txtManganese.Text)
If ((Carbon >= 0.2 And Carbon <= 0.29) And (Manganese >= 0.25
And Manganese <= 1.7)) Then
    MaterialType = "LOW CARBON STEEL"
    txtMaterialType.Text = MaterialType

ElseIf ((Carbon >= 0.3 And Carbon <= 0.59) And
(Manganese >= 0.25 And Manganese <= 1.7)) Then
    MaterialType = "MEDIUM CARBON STEEL"
    txtMaterialType.Text = MaterialType
    'frmsteel.Show
ElseIf ((Carbon >= 0.6 And Carbon <= 0.9) And
(Manganese >= 0.25 And Manganese <= 1.7)) Then
    MaterialType = "HIGH CARBON STEEL"
    txtMaterialType.Text = MaterialType
Else: MaterialType = "NON CARBON STEEL"
    txtMaterialType.Text = MaterialType
    MaterialType = txtMaterialType.Text
End If

End Sub

Private Sub Text1_Change()

End Sub

Private Sub Label1_Click()

End Sub

Private Sub Command1_Click()
Dim Carbon, Manganese As Single
Dim MaterialType As String
Carbon = Val(txtCarbon.Text)
Manganese = Val(txtManganese.Text)
If ((Carbon >= 0.3 And Carbon <= 0.59) And (Manganese >= 0.25
And Manganese <= 1.7)) Then

```

```
MaterialType = "MEDIUM CARBON STEEL"  
frmsteel.Show  
Else  
End  
End If
```

```
End Sub
```

```
Private Sub Command2_Click()  
End
```

```
End Sub
```

```
Option Explicit
```

```
Public LoginSucceeded As Boolean
```

```
Private Sub cmdCancel_Click()  
    'set the global var to false  
    'to denote a failed login  
    LoginSucceeded = False  
    Me.Hide  
End Sub
```

```
Private Sub cmdOK_Click()  
    'check for correct password  
    If txtPassword = "management" Then  
        'place code to here to pass the  
        'success to the calling sub  
        'setting a global var is the easiest  
        LoginSucceeded = True  
        frmMaterialType.Show  
        Me.Hide  
    Else  
        MsgBox "Invalid Password, try again!", , "Login"  
        txtPassword.SetFocus  
        SendKeys "{Home}+{End}"  
    End If  
End Sub
```

```
Private Sub About_Click()  
frmAbout.Show  
End Sub
```

```
Private Sub cmdEnd_Click()  
End  
End Sub  
Private Sub cmdIS_Click()
```

```
frmImpactStrength.Show
frmLHV.Hide
frmTHV.Hide
frmTSB.Hide
frmTSM.Hide
frmYieldStrength.Hide
End Sub
Private Sub cmdLHV_Click()
frmLHV.Show
frmImpactStrength.Hide
frmTHV.Hide
frmTSB.Hide
frmTSM.Hide
frmYieldStrength.Hide
```

```
End Sub
Private Sub cmdTHV_Click()
frmTHV.Show
frmImpactStrength.Hide
frmLHV.Hide
frmTSB.Hide
frmTSM.Hide
frmYieldStrength.Hide
```

```
End Sub
Private Sub cmdTS_B_Click()
frmTSB.Show
frmImpactStrength.Hide
frmLHV.Hide
frmTHV.Hide
frmTSM.Hide
frmYieldStrength.Hide
```

```
End Sub
Private Sub cmdYS_Click()
frmYieldStrength.Show
frmImpactStrength.Hide
frmLHV.Hide
frmTHV.Hide
frmTSB.Hide
frmTSM.Hide
```

```
End Sub
Private Sub cmTS_M_Click()
frmTSM.Show
frmImpactStrength.Hide
frmLHV.Hide
frmTHV.Hide
frmTSB.Hide
frmYieldStrength.Hide
```

End Sub

```
Private Sub IS_Click()  
frmImpactStrength.Show  
frmLHV.Hide  
frmTHV.Hide  
frmTSB.Hide  
frmTSM.Hide  
frmYieldStrength.Hide
```

End Sub

```
Private Sub LHV_Click()  
frmLHV.Show  
frmImpactStrength.Hide  
frmTHV.Hide  
frmTSB.Hide  
frmTSM.Hide  
frmYieldStrength.Hide
```

End Sub

```
Private Sub Quit_Click()  
End  
End Sub
```

```
Private Sub Steel_Click()  
frmSteel.Show  
End Sub
```

```
Private Sub THV_Click()  
frmTHV.Show  
frmImpactStrength.Hide  
frmLHV.Hide  
frmTSB.Hide  
frmTSM.Hide  
frmYieldStrength.Hide
```

End Sub

```
Private Sub Tip_Click()  
frmTip.Show  
End Sub
```

```
Private Sub TSB_Click()  
frmTSB.Show  
frmImpactStrength.Hide  
frmLHV.Hide  
frmTHV.Hide  
frmTSM.Hide
```

frmYieldStrength.Hide

End Sub

Private Sub TSML_Click()

frmTsmL.Show

frmImpactStrength.Hide

frmLHV.Hide

frmTHV.Hide

frmTSB.Hide

frmYieldStrength.Hide

End Sub

Private Sub Uses_Click()

frmUses.Show

End Sub

Private Sub YS_Click()

frmYieldStrength.Show

frmImpactStrength.Hide

frmLHV.Hide

frmTHV.Hide

frmTSB.Hide

frmTsmL.Hide

End Sub

Private Sub cmdCancel_Click()

txtDiameter.Text = ""

txtC.Text = ""

txtMn.Text = ""

txtSi.Text = ""

txtP.Text = ""

txtS.Text = ""

txtCr.Text = ""

txtNi.Text = ""

txtCu.Text = ""

txtCo.Text = ""

txtW.Text = ""

txtFe.Text = ""

txtImpactStrength.Text = ""

End Sub

Private Sub cmdCompute_Click()

Dim Carbon, Manganese, Silicon, Phosphorus, Sulphur As Double

Dim Chromium, Nickel, Copper, Cobalt, Tungsten, Iron As Double

Dim Diameter, ImpactStrength As Double

Diameter = txtDiameter.Text

Carbon = txtC.Text

```

Manganese = txtMn.Text
Silicon = txtSi.Text
Phosphorus = txtP.Text
Sulphur = txtS.Text
Chromium = txtCr.Text
Nickel = txtNi.Text
Copper = txtCu.Text
Cobolt = txtCo.Text
Tungsten = txtW.Text
Iron = txtFe.Text
' Compute the value for different model option
If optModel1.Value = True Then
    ImpactStrength = 49533.516 + (18.746 * Diameter) + (-3143.437 * Carbon)
    + (-1210.22 * Manganese) + (293.275 * Silicon) + (10289.649 * Phosphorus)
    + (-2665.425 * Sulphur) + (-596.001 * Nickel) + (-1908.336 * Copper) + (-5937.968
    * Cobolt)
    + (1756.776 * Tungsten) + (-486.748 * Iron)
Else
    ImpactStrength = 876.043 + (19.182 * Diameter) + (-2720.612 * Carbon)
    + (-721.811 * Manganese) + (776.895 * Silicon) + (10729.154 * Phosphorus)
    + (-2109.33 * Sulphur) + (489.975 * Chromium) + (-107.512 * Nickel) + (-1417.534
    * Copper)
    + (-5446.725 * Cobolt) + (2212.546 * Tungsten)
End If
txtImpactStrength.Text = ImpactStrength

End Sub

Private Sub cmdExit_Click()
End
End Sub
Private Sub cmdProperty_Click()
frmsteel.Show
End Sub
Private Sub optModel1_Click()
If optModel1.Value = True Then
    txtCr.Enabled = False
    'txtCr.Text = ""
    txtFe.Enabled = True
End If
'Call Model
End Sub
Private Sub optModel2_Click()
If optModel2.Value = True Then
    txtFe.Enabled = False
    'txtFe.Text = ""
    txtCr.Enabled = True
End If
'Call Model
End Sub

```

```

Private Sub cmdCancel_Click()
txtDiameter.Text = ""
txtC.Text = ""
txtMn.Text = ""
txtSi.Text = ""
txtP.Text = ""
txtS.Text = ""
txtCr.Text = ""
txtNi.Text = ""
txtCu.Text = ""
txtCo.Text = ""
txtW.Text = ""
txtFe.Text = ""
txtLHV.Text = ""
End Sub

```

```

Private Sub cmdCompute_Click()
Dim Carbon, Manganese, Silicon, Phosphorus, Sulphur As Double
Dim Chromium, Nickel, Copper, Cobolt, Tungsten, Iron As Double
Dim Diameter, LHV As Double
Diameter = txtDiameter.Text
Carbon = txtC.Text
Manganese = txtMn.Text
Silicon = txtSi.Text
Phosphorus = txtP.Text
Sulphur = txtS.Text
Chromium = txtCr.Text
Nickel = txtNi.Text
Copper = txtCu.Text
Cobolt = txtCo.Text
Tungsten = txtW.Text
Iron = txtFe.Text
' Compute the value for different model option
If optModel1.Value = True Then
LHV = -10185.1 + (-3.978 * Diameter) + (478.255 * Carbon) + (-94.675 *
Manganese) + (217.623 * Silicon)
+ (454.022 * Phosphorus) + (-2576.025 * Sulphur)
+ (129.133 * Nickel) + (-858.781 * Copper) + (-1436.09 * Cobolt) + (1245.566 *
Tungsten) + (104.783 * Iron)
Else
LHV = 289.3607 + (-4.012 * Diameter) + (387.232 * Carbon) + (-199.816 *
Manganese)
+ (113.513 * Silicon) + (359.407 * Phosphorus) + (-2695.735 * Sulphur) + (-105.478
* Chromium)
+ (23.974 * Nickel) + (-964.437 * Copper) + (-1541.841 * Cobolt) + (1147.451 *
Tungsten)
End If
txtLHV.Text = LHV

End Sub

```

```

Private Sub cmdExit_Click()
End
End Sub
Private Sub cmdProperty_Click()
frmsteel.Show
End Sub
Private Sub optModel1_Click()
If optModel1.Value = True Then
    txtCr.Enabled = False
    'txtCr.Text = ""
    txtFe.Enabled = True
End If
'Call Model
End Sub
Private Sub optModel2_Click()
If optModel2.Value = True Then
    txtFe.Enabled = False
    'txtFe.Text = ""
    txtCr.Enabled = True
End If
'Call Model
End Sub

```

```

Private Sub cmdCancel_Click()
txtDiameter.Text = ""
txtC.Text = ""
txtMn.Text = ""
txtSi.Text = ""
txtP.Text = ""
txtS.Text = ""
txtCr.Text = ""
txtNi.Text = ""
txtCu.Text = ""
txtCo.Text = ""
txtW.Text = ""
txtFe.Text = ""
txtTSB.Text = ""
End Sub

```

```

Private Sub cmdCompute_Click()
Dim Carbon, Manganese, Silicon, Phosphorus, Sulphur As Double
Dim Chromium, Nickel, Copper, Cobolt, Tungsten, Iron As Double
Dim Diameter, TSB As Double
Diameter = txtDiameter.Text
Carbon = txtC.Text
Manganese = txtMn.Text
Silicon = txtSi.Text
Phosphorus = txtP.Text
Sulphur = txtS.Text
Chromium = txtCr.Text

```

```

Nickel = txtNi.Text
Copper = txtCu.Text
Cobolt = txtCo.Text
Tungsten = txtW.Text
Iron = txtFe.Text
' Compute the value for different model option
If optModel1.Value = True Then
TSB = 29685.912 + (-24.84 * Diameter) + (6672.319 * Carbon) + (-2449.659 *
Manganese)
+ (1983.252 * Silicon) + (23344.305 * Phosphorus) + (-15350.3 * Sulphur) + (-
1043.603 * Nickel)
+ (-5179.974 * Copper) + (-13607.1 * Cobolt) + (8505.157 * Tungsten) + (-303.993 *
Iron)
Else
TSB = -702.189 + (-24.567 * Diameter) + (6936.389 * Carbon) + (-2144.629 *
Manganese)
+ (2285.292 * Silicon) + (23618.798 * Phosphorus) + (-15003# * Sulphur) + (306.008
* Chromium)
+ (-738.523 * Nickel) + (-4873.448 * Copper) + (-13300.3 * Cobolt) + (8789.803 *
Tungsten)
End If
txtTSB.Text = TSB

End Sub

Private Sub cmdExit_Click()
End
End Sub
Private Sub cmdProperty_Click()
frmsteel.Show
End Sub
Private Sub optModel1_Click()
If optModel1.Value = True Then
txtCr.Enabled = False
txtCr.Text = ""
txtFe.Enabled = True
End If
'Call Model
End Sub
Private Sub optModel2_Click()
If optModel2.Value = True Then
txtFe.Enabled = False
txtFe.Text = ""
txtCr.Enabled = True
End If
'Call Model
End Sub

```

```

Private Sub cmdCancel_Click()
txtDiameter.Text = ""
txtC.Text = ""
txtMn.Text = ""
txtSi.Text = ""
txtP.Text = ""
txtS.Text = ""
txtCr.Text = ""
txtNi.Text = ""
txtCu.Text = ""
txtCo.Text = ""
txtW.Text = ""
txtFe.Text = ""
txtTSML.Text = ""
End Sub

```

```

Private Sub cmdCompute_Click()
Dim Carbon, Manganese, Silicon, Phosphorus, Sulphur As Double
Dim Chromium, Nickel, Copper, Cobolt, Tungsten, Iron As Double
Dim Diameter, TSML As Double
Diameter = txtDiameter.Text
Carbon = txtC.Text
Manganese = txtMn.Text
Silicon = txtSi.Text
Phosphorus = txtP.Text
Sulphur = txtS.Text
Chromium = txtCr.Text
Nickel = txtNi.Text
Copper = txtCu.Text
Cobolt = txtCo.Text
Tungsten = txtW.Text
Iron = txtFe.Text
' Compute the value for different model option
If optModel1.Value = True Then
TSML = 94603.105 + (-40.236 * Diameter) + (8869.178 * Carbon) + (-4228.685 *
Manganese)
+ (2683.913 * Silicon) + (42726.779 * Phosphorus) + (-18345.1 * Sulphur) + (-
2392.061 * Nickel)
+ (-6662.409 * Copper) + (-20887.8 * Cobolt) + (12707.265 * Tungsten) + (-965.3 *
Iron)
Else
TSML = -1891.43 + (-39.37 * Diameter) + (9707.708 * Carbon) + (-3260.09 *
Manganese)
+ (3643.01 * Silicon) + (43598.406 * Phosphorus) + (-17242.3 * Sulphur) + (971.7 *
Chromium)
+ (-1423.307 * Nickel) + (-5689.067 * Copper) + (-19913.6 * Cobolt) + (13611.132
* Tungsten)
End If
txtTSML.Text = TSML

```

End Sub

Private Sub cmdExit_Click()

End

End Sub

Private Sub cmdProperty_Click()

frmsteel.Show

End Sub

Private Sub optModel1_Click()

If optModel1.Value = True Then

txtCr.Enabled = False

txtCr.Text = ""

txtFe.Enabled = True

End If

'Call Model

End Sub

Private Sub optModel2_Click()

If optModel2.Value = True Then

txtFe.Enabled = False

txtFe.Text = ""

txtCr.Enabled = True

End If

'Call Model

End Sub

Private Sub cmdCancel_Click()

txtDiameter.Text = ""

txtC.Text = ""

txtMn.Text = ""

txtSi.Text = ""

txtP.Text = ""

txtS.Text = ""

txtCr.Text = ""

txtNi.Text = ""

txtCu.Text = ""

txtCo.Text = ""

txtW.Text = ""

txtFe.Text = ""

txtYieldStrength.Text = ""

End Sub

Private Sub cmdCompute_Click()

Dim Carbon, Manganese, Silicon, Phosphorus, Sulphur As Double

Dim Chromium, Nickel, Copper, Cobalt, Tungsten, Iron As Double

Dim Diameter, YieldStrength As Double

Diameter = txtDiameter.Text

Carbon = txtC.Text

Manganese = txtMn.Text

Silicon = txtSi.Text

Phosphorus = txtP.Text

Sulphur = txtS.Text

```

Chromium = txtCr.Text
Nickel = txtNi.Text
Copper = txtCu.Text
Cobolt = txtCo.Text
Tungsten = txtW.Text
Iron = txtFe.Text
' Compute the value for different model option
If optModel1.Value = True Then
    YieldStrength = 18771.779 + (-47.062 * Diameter) + (6806.016 * Carbon)
    + (-2642.321 * Manganese) + (2267.215 * Silicon) + (26006.971 * Phosphorus)
    + (-17867.7 * Sulphur) + (-1080.794 * Nickel) + (-6223.144 * Copper) + (-15487# *
Cobolt)
    + (11112.811 * Tungsten) + (-190.116 * Iron)
Else
    YieldStrength = -232.782 + (-46.891 * Diameter) + (6971.164 * Carbon)
    + (-2451.557 * Manganese) + (2456.109 * Silicon) + (26178.638 * Phosphorus)
    + (-17650.5 * Sulphur) + (191.376 * Chromium) + (-889.998 * Nickel) + (-6031.445
* Copper)
    + (-15295.1 * Cobolt) + (11290.827 * Tungsten)
End If
txtYieldStrength.Text = YieldStrength

End Sub

Private Sub cmdExit_Click()
End
End Sub
Private Sub cmdProperty_Click()
frmsteel.Show
End Sub
Private Sub optModel1_Click()
If optModel1.Value = True Then
    txtCr.Enabled = False
    'txtCr.Text = ""
    txtFe.Enabled = True
End If
'Call Model
End Sub
Private Sub optModel2_Click()
If optModel2.Value = True Then
    txtFe.Enabled = False
    'txtFe.Text = ""
    txtCr.Enabled = True
End If
'Call Model
End Sub

```

MODELS RESULTS

Regression Model for Transverse Hardness Value

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	X11 %W, X9 %Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr		Enter

a. All requested variables entered.

b. Dependent Variable: Y1 TRANSVERSE HARDNESS VALUE (THV)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000 ^a	1.000		

a. Predictors: (Constant), X11 %W, X9 %Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	79.057	.000			
	X1 DIAMETER (mm)	-3.200	.000	-6.733		
	X2 %C	292.132	.000	3.204		
	X3 %Mn	1.789	.000	.034		
	X4 %Si	-24.753	.000	-.348		
	X5 %P	-1259.459	.000	-5.465		
	X6 %S	-598.514	.000	-2.736		
	X7 %Cr	-89.020	.000	-12.071		
	X8 %Ni	-36.112	.000	-.418		
	X9 %Cu	-108.391	.000	-.609		
	X10 %Co	192.169	.000	.583		
	X11 %W	160.011	.000	1.188		

a. Dependent Variable: Y1 TRANSVERSE HARDNESS VALUE (THV)

Regression Model for Longitudinal Hardness Value

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr		Enter

a. All requested variables entered.

b. Dependent Variable: Y2 LONGITUDINAL HARDNESS VALUE (LHV)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000 ^a	1.000		

a. Predictors: (Constant), X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	88.437	11	8.040		^a
	Residual	.000	0			
	Total	88.437	11			

a. Predictors: (Constant), X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr

b. Dependent Variable: Y2 LONGITUDINAL HARDNESS VALUE (LHV)

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	289.360	.000			
	X1 DIAMETER (mm)	-4.012	.000	-7.117		
	X2 %C	387.232	.000	3.580		
	X3 %Mn	-199.816	.000	-3.241		
	X4 %Si	113.513	.000	1.346		
	X5 %P	359.407	.000	1.315		
	X6 %S	-2695.735	.000	-10.390		
	X7 %Cr	-105.478	.000	-12.060		
	X8 %Ni	23.974	.000	.234		
	X9 % Cu	-964.437	.000	-4.572		
	X10 %Co	-1541.841	.000	-3.943		
	X11 %W	1147.451	.000	7.184		

a. Dependent Variable: Y2 LONGITUDINAL HARDNESS VALUE (LHV)

Regression Model for Tensile Strength at Maximum Load

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr		Enter

a. All requested variables entered.

b. Dependent Variable: Y3 TS@max

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000 ^a	1.000		

a. Predictors: (Constant), X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	39403.772	11	3582.161		*
	Residual	.000	0			
	Total	39403.772	11			

a. Predictors: (Constant), X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr

b. Dependent Variable: Y3 TS@max

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1891.430	.000			
	X1 DIAMETER (mm)	-39.370	.000	-3.308		
	X2 %C	9707.708	.000	4.252		
	X3 %Mn	-3260.090	.000	-2.505		
	X4 %Si	3643.010	.000	2.046		
	X5 %P	43598.406	.000	7.556		
	X6 %S	-17242.3	.000	-3.148		
	X7 %Cr	971.700	.000	5.263		
	X8 %Ni	-1423.307	.000	-.658		
	X9 % Cu	-5689.067	.000	-1.278		
	X10 %Co	-19913.6	.000	-2.412		
	X11 %W	13611.132	.000	4.037		

a. Dependent Variable: Y3 TS@max

Regression Model for Tensile Strength at Break

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr		Enter

a. All requested variables entered.

b. Dependent Variable: Y4 T S@break

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000 ^a	1.000		

a. Predictors: (Constant), X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	64178.059	11	5834.369		^a
	Residual	.000	0			
	Total	64178.059	11			

a. Predictors: (Constant), X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr

b. Dependent Variable: Y4 T S@break

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-702.189	.000			
	X1 DIAMETER (mm)	-24.567	.000	-1.618		
	X2 %C	6936.389	.000	2.381		
	X3 %Mn	-2144.629	.000	-1.291		
	X4 %Si	2285.292	.000	1.006		
	X5 %P	23618.798	.000	3.208		
	X6 %S	-15003.0	.000	-2.146		
	X7 %Cr	306.008	.000	1.299		
	X8 %Ni	-738.523	.000	-.268		
	X9 % Cu	-4873.448	.000	-.858		
	X10 %Co	-13300.3	.000	-1.262		
	X11 %W	8789.803	.000	2.043		

a. Dependent Variable: Y4 T S@break

Regression Model for Yield Strength (Y.S)

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr		Enter

- a. All requested variables entered.
b. Dependent Variable: Y5 YIELD STRENGTH (Y.S)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000 ^a	1.000		

- a. Predictors: (Constant), X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8415.832	11	765.076		. ^a
	Residual	.000	0			
	Total	8415.832	11			

- a. Predictors: (Constant), X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr
b. Dependent Variable: Y5 YIELD STRENGTH (Y.S)

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-232.782	.000			
	X1 DIAMETER (mm)	-46.891	.000	-8.526		
	X2 %C	6971.164	.000	6.607		
	X3 %Mn	-2451.557	.000	-4.076		
	X4 %Si	2456.109	.000	2.985		
	X5 %P	26178.638	.000	9.818		
	X6 %S	-17650.5	.000	-6.974		
	X7 %Cr	191.376	.000	2.243		
	X8 %Ni	-889.998	.000	-.891		
	X9 % Cu	-6031.445	.000	-2.931		
	X10 %Co	-15295.1	.000	-4.009		
	X11 %W	11290.827	.000	7.247		

- a. Dependent Variable: Y5 YIELD STRENGTH (Y.S)

Regression Model for Impact Strength

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Tungsten, Copper, Diameter, Manganese, Silicon, Phosphorus, Cobalt, Nickel, Carbon, Sulphur, Chromium		Enter

a. All requested variables entered.

b. Dependent Variable: Impact Strength

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000 ^a	1.000		

a. Predictors: (Constant), Tungsten, Copper, Diameter, Manganese, Silicon, Phosphorus, Cobalt, Nickel, Carbon, Sulphur, Chromium

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6372.667	11	579.333		
	Residual	.000	0			
	Total	6372.667	11			

a. Predictors: (Constant), Tungsten, Copper, Diameter, Manganese, Silicon, Phosphorus, Cobalt, Nickel, Carbon, Sulphur, Chromium

b. Dependent Variable: Impact Strength

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	876.643	.000			
	Diameter	19.182	.000	4.008		
	Carbon	-2720.612	.000	-2.963		
	Manganese	-721.811	.000	-1.379		
	Silicon	776.895	.000	1.085		
	Phosphorus	10729.154	.000	4.624		
	Sulphur	-2109.332	.000	-.958		
	Chromium	489.975	.000	6.599		
	Nickel	-107.512	.000	-.124		
	Copper	-1417.534	.000	-.792		
	Cobalt	-5446.725	.000	-1.641		
	Tungsten	2212.546	.000	1.632		

a. Dependent Variable: Impact Strength

Regression Model for Transverse Hardness Value

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	X12 %Fe, X9 %Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P ^a		Enter

a. Tolerance = .000 limits reached.

b. Dependent Variable: Y1 TRANSVERSE HARDNESS VALUE (THV)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000 ^a	1.000	.	.

a. Predictors: (Constant), X12 %Fe, X9 %Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	62.870	11	5.715		^a
	Residual	.000	0			
	Total	62.870	11			

a. Predictors: (Constant), X12 %Fe, X9 %Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y1 TRANSVERSE HARDNESS VALUE (THV)

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-8761.045	.000			
	X1 DIAMETER (mm)	-3.121	.000	-6.566		
	X2 %C	368.952	.000	4.046		
	X3 %Mn	90.524	.000	1.741		
	X4 %Si	63.113	.000	.887		
	X5 %P	-1179.607	.000	-5.118		
	X6 %S	-497.482	.000	-2.274		
	X8 %Ni	52.638	.000	.609		
	X9 %Cu	-19.221	.000	-.108		
	X10 %Co	281.419	.000	.853		
	X11 %W	242.816	.000	1.803		
	X12 %Fe	88.434	.000	11.750		

a. Dependent Variable: Y1 TRANSVERSE HARDNESS VALUE (THV)

Excluded Variables^a

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	X7 %Cr	^a			.000

a. Predictors in the Model: (Constant), X12 %Fe, X9 %Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y1 TRANSVERSE HARDNESS VALUE (THV)

Regression Model for Longitudinal Hardness Value

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	X12 %Fe, X9 %Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P		Enter

a. Tolerance = .000 limits reached.

b. Dependent Variable: Y2 LONGITUDINAL HARDNESS VALUE (LHV)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000 ^a	1.000		

a. Predictors: (Constant), X12 %Fe, X9 %Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	88.437	11	8.040		. ^a
	Residual	.000	0			
	Total	88.437	11			

a. Predictors: (Constant), X12 %Fe, X9 %Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y2 LONGITUDINAL HARDNESS VALUE (LHV)

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-10185.1	.000			
	X1 DIAMETER (mm)	-3.918	.000	-6.950		
	X2 %C	476.255	.000	4.422		
	X3 %Mn	-94.675	.000	-1.536		
	X4 %Si	217.623	.000	2.580		
	X5 %P	454.022	.000	1.661		
	X6 %S	-2576.025	.000	-9.928		
	X8 %Ni	129.133	.000	1.261		
	X9 %Cu	-858.781	.000	-4.071		
	X10 %Co	-1436.090	.000	-3.672		
	X11 %W	1245.566	.000	7.799		
	X12 %Fe	104.783	.000	11.739		

a. Dependent Variable: Y2 LONGITUDINAL HARDNESS VALUE (LHV)

Excluded Variables^b

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	X7 %Cr	. ^a			.000

a. Predictors in the Model: (Constant), X12 %Fe, X9 %Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y2 LONGITUDINAL HARDNESS VALUE (LHV)

Regression Model for Tensile Strength at Maximum Load

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P ^a		Enter

a. Tolerance = .000 limits reached.

b. Dependent Variable: Y3 TS@max

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000 ^a	1.000		

a. Predictors: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	39403.772	11	3582.161		^a
	Residual	.000	0			
	Total	39403.772	11			

a. Predictors: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y3 TS@max

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	54503.105	.000			
	X1 DIAMETER (mm)	-40.236	.000	-3.381		
	X2 %C	8869.178	.000	3.885		
	X3 %Mn	-4228.685	.000	-3.249		
	X4 %Si	2683.913	.000	1.507		
	X5 %P	42726.775	.000	7.405		
	X6 %S	-18345.1	.000	-3.350		
	X8 %Ni	-2392.061	.000	-1.106		
	X9 % Cu	-6652.409	.000	-1.496		
	X10 %Co	-20887.8	.000	-2.530		
	X11 %W	12707.265	.000	3.769		
	X12 %Fe	-965.300	.000	-5.123		

a. Dependent Variable: Y3 TS@max

Excluded Variables^b

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
					Tolerance
1	X7 %Cr	^a			.000

a. Predictors in the Model: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y3 TS@max

Regression Model for Tensile Strength at Break

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P		Enter

a. Tolerance = .000 limits reached.

b. Dependent Variable: Y4 T S@break

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000 ^a	1.000	-	-

a. Predictors: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	64178.059	11	5834.369		^a
	Residual	.000	0			
	Total	64178.059	11			

a. Predictors: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y4 T S@break

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	23685.912	.000			
	X1 DIAMETER (mm)	-24.840	.000	-1.636		
	X2 %C	6672.319	.000	2.290		
	X3 %Mn	-2449.859	.000	-1.475		
	X4 %Si	1983.252	.000	.873		
	X5 %P	23344.306	.000	3.170		
	X6 %S	-15350.3	.000	-2.196		
	X8 %Ni	-1043.603	.000	-.378		
	X9 % Cu	-5179.974	.000	-.912		
	X10 %Co	-13607.1	.000	-1.292		
	X11 %W	8505.157	.000	1.977		
	X12 %Fe	-303.993	.000	-1.264		

a. Dependent Variable: Y4 T S@break

Excluded Variables^b

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	X7 %Cr	^a			.000

a. Predictors in the Model: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y4 T S@break

Regression Model for Yield Strength (Y.S)

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	X12 %Fe, X9 %Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P ^a		Enter

a. Tolerance = .000 limits reached.

b. Dependent Variable: Y5 YIELD STRENGTH (Y.S)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000 ^a	1.000		

a. Predictors: (Constant), X12 %Fe, X9 %Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8415.832	11	765.076		^a
	Residual	.000	0			
	Total	8415.832	11			

a. Predictors: (Constant), X12 %Fe, X9 %Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y5 YIELD STRENGTH (Y.S)

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	18771.779	.000			
	X1 DIAMETER (mm)	-47.062	.000	-8.557		
	X2 %C	6806.016	.000	6.451		
	X3 %Mn	-2642.321	.000	-4.393		
	X4 %Si	2267.215	.000	2.755		
	X5 %P	28006.971	.000	9.753		
	X6 %S	-17867.7	.000	-7.059		
	X8 %Ni	-1080.794	.000	-1.082		
	X9 %Cu	-6223.144	.000	-3.024		
	X10 %Co	-15487.0	.000	-4.060		
	X11 %W	11112.811	.000	7.133		
	X12 %Fe	-190.118	.000	-2.183		

a. Dependent Variable: Y5 YIELD STRENGTH (Y.S)

Excluded Variables^b

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	X7 %Cr ^a				.000

a. Predictors in the Model: (Constant), X12 %Fe, X9 %Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y5 YIELD STRENGTH (Y.S)

Regression Model for Impact Strength

Variables Entered/Removed^b

Model	Variables Entered	Variables Removed	Method
1	Iron, Copper, Nickel, Tungsten, Silicon, Carbon, Cobalt, Manganese, Sulphur, Diameter, Phosphorus ^a		Enter

a. Tolerance = .000 limits reached.

b. Dependent Variable: Impact Strength

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000 ^a	1.000		

a. Predictors: (Constant), Iron, Copper, Nickel, Tungsten, Silicon, Carbon, Cobalt, Manganese, Sulphur, Diameter, Phosphorus

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6372.667	11	579.333		^a
	Residual	.000	0			
	Total	6372.667	11			

a. Predictors: (Constant), Iron, Copper, Nickel, Tungsten, Silicon, Carbon, Cobalt, Manganese, Sulphur, Diameter, Phosphorus

b. Dependent Variable: Impact Strength

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	49533.516	.000			
	Diameter	18.746	.000	3.917		
	Carbon	-3143.437	.000	-3.424		
	Manganese	-1210.220	.000	-2.312		
	Silicon	293.275	.000	.410		
	Phosphorus	10289.641	.000	4.435		
	Sulphur	-2665.421	.000	-1.210		
	Nickel	-596.001	.000	-.685		
	Copper	-1908.336	.000	-1.066		
	Cobalt	-5937.968	.000	-1.789		
	Tungsten	1756.776	.000	1.296		
	Iron	-486.748	.000	-.6424		

a. Dependent Variable: Impact Strength

Excluded Variables^b

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	Chromium	^a			.000

a. Predictors in the Model: (Constant), Iron, Copper, Nickel, Tungsten, Silicon, Carbon, Cobalt, Manganese, Sulphur, Diameter, Phosphorus

b. Dependent Variable: Impact Strength

TENSILE TESTS RESULTS

Medium carbon steel rods

Medium carbon steel rods

RDO

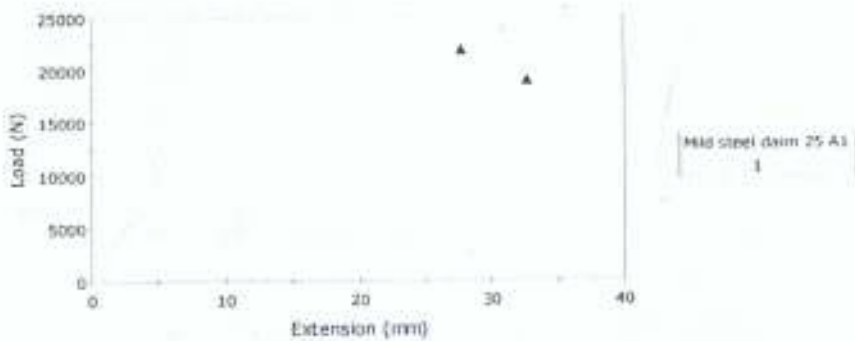
Operator ID	
Company	Engineering Materials Development Institute
Laboratory Name	Mechanical Testing Laboratory
Rate 1	10.00000 mm/min
Humidity (%)	50.00000
Temperature (deg C)	27.00

Engineering Materials Development Institute

Km 4 Ondo Road P.M.B. 611 Akure 340001

email: director@emdi.gov.ng

Mild steel diam 25mm A1



	Specimen label	Load at Break (Standard) (N)	Maximum Load (N)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (%)
1	Mild Steel samples	18976.14	21848.03	772.72	213.72	671.14	251.93

	Tensile stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)	Extension at Break (Standard) (mm)	Energy at Break (Standard) (J)
1	772.72	2121.40	32.75046	551.54060

	Tensile extension at Break (Standard) (mm)	Area (cm^2)	Diameter (mm)	Length (mm)
1	32.75046	0.28274	6.00000	13.00000

	True strain at Maximum Load (mm/mm)	True stress at Maximum Load (Pa)	Poisson's Ratio (Chord)	Energy at Yield (Zero Slope) (J)
1	1.14333	2424155378.48114	---	445.83299

	Extension at Yield (Zero Slope) (mm)	Load at Yield (Zero Slope) (N)
1	27.78343	21848.03486

Medium carbon steel rods

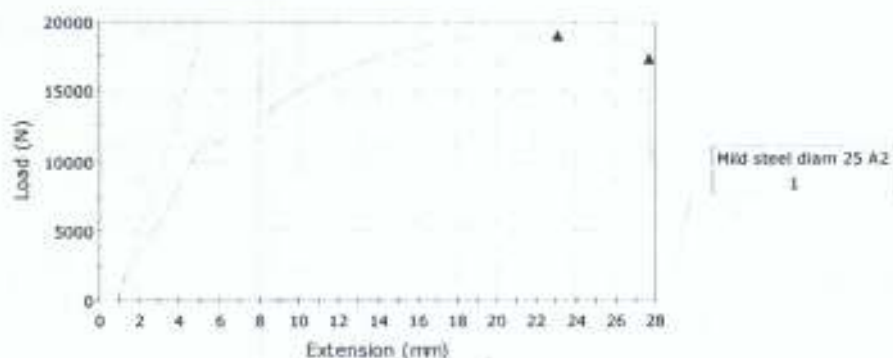
Medium carbon steel rods

Operator ID	RDO	
Company	Engineering Materials Development Institute	
Laboratory Name	Mechanical Testing Laboratory	Engineering
Rate I	10.00000 mm/min	g
Humidity (%)	50.00000	Materials
Temperature (deg C)	27.00	Development
Institute		ent

Km 4 Ondo Road P.M.B. 611 Akure 340001

email: director@emdi.gov.ng

Mild steel diam 25mm A2



	Specimen label	Load at Break (Standard) (N)	Maximum Load (N)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (%)
1	Mild Steel samples	17300.11	19053.35	673.87	177.75	611.87	212.95

	Tensile stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)	Extension at Break (Standard) (mm)	Energy at Break (Standard) (J)
1	673.87	2095.34	27.68328	406.69883

	Tensile extension at Break (Standard) (mm)	Area (cm ²)	Diameter (mm)	Length (mm)
1	27.68328	0.28274	6.00000	13.00000

	True strain at Maximum Load (mm/mm)	True stress at Maximum Load (Pa)	Poisson's Ratio (Chord)	Energy at Yield (Zero Slope) (J)
1	1.02157	1871718721.34550	---	321.12487

	Extension at Yield (Zero Slope) (mm)	Load at Yield (Zero Slope) (N)
1	23.10812	19053.35337

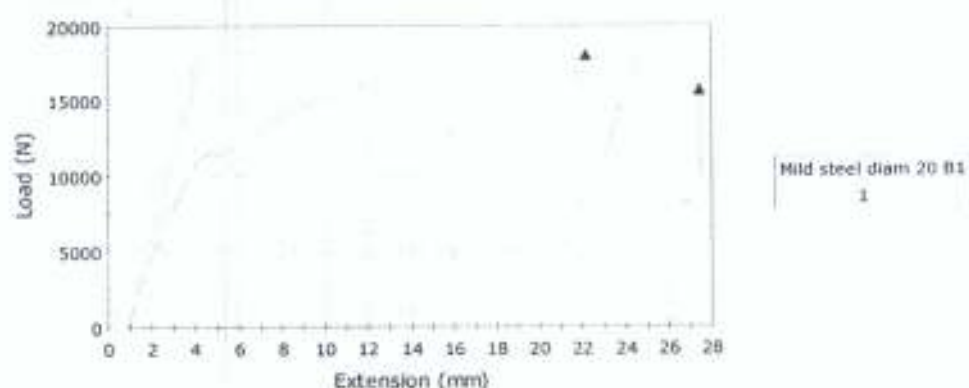
Operator ID
CompanyLaboratory Name
Rate 1
Humidity (%)
Temperature (deg C)RDO
Engineering Materials Development
Institute
Mechanical Testing Laboratory
10.00000 mm/min
50.00000
27.00

Engineering Materials Development Institute

Km 4 Ondo Road P.M.B. 611 Akure 340001

email: director@emdi.gov.ng

Mild steel diam 20mm B1



Specimen label	Load at Break (Standard) (N)	Maximum Load (N)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (%)
1 Mild Steel samples	15602.91	18040.82	638.06	170.52	551.84	211.03

	Tensile stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)	Extension at Break (Standard) (mm)	Energy at Break (Standard) (J)
1	638.06	2414.22	27.43343	396.80670

	Tensile extension at Break (Standard) (mm)	Area (cm ²)	Diameter (mm)	Length (mm)
1	27.43344	0.28274	6.00000	13.00000

	True strain at Maximum Load (mm/mm)	True stress at Maximum Load (Pa)	Poisson's Ratio (Chord)	Energy at Yield (Zero Slope) (J)
1	0.99516	1726061050.13328	---	304.98226

	Extension at Yield (Zero Slope) (mm)	Load at Yield (Zero Slope) (N)
1	22.16703	18040.81798

Medium carbon steel rods

Medium carbon steel rods

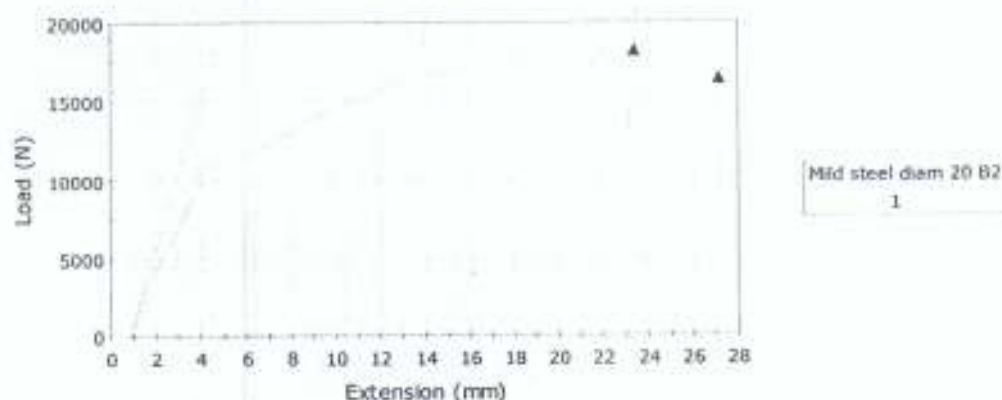
Operator ID	RDO
Company	Engineering Materials Development Institute
Laboratory Name	Mechanical Testing Laboratory
Rate I	10.00000 mm/min
Humidity (%)	50.00000
Temperature (deg C)	27.00

Engineering Materials Development Institute

Km 4 Ondo Road P.M.B. 611 Akure 340001

email: director@emdi.gov.ng

Mild steel diam 20mm B2



	Specimen label	Load at Break (Standard) (N)	Maximum Load (N)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (%)
1	Mild Steel samples	16392.99	18227.56	644.67	180.13	579.78	208.78

	Tensile stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)	Extension at Break (Standard) (mm)	Energy at Break (Standard) (J)
1	644.67	2221.83	27.14187	386.59179

	Tensile extension at Break (Standard) (mm)	Area (cm ²)	Diameter (mm)	Length (mm)
1	27.14187	0.28274	6.00000	13.00000

	True strain at Maximum Load (mm/mm)	True stress at Maximum Load (Pa)	Poisson's Ratio (Chord)	Energy at Yield (Zero Slope) (J)
1	1.03008	1805899121.37140	---	320.37488

	Extension at Yield (Zero Slope) (mm)	Load at Yield (Zero Slope) (N)
1	23.41671	18227.55635

Medium carbon steel rods

Medium carbon steel rods

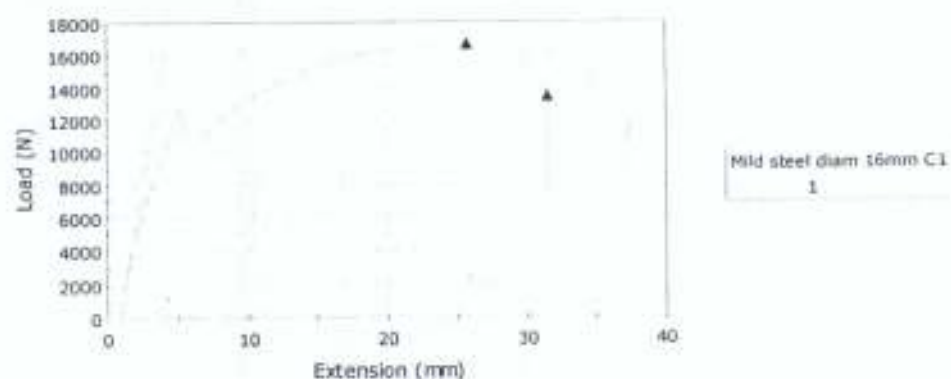
Operator ID	RDO
Company	Engineering Materials Development Institute
Laboratory Name	Mechanical Testing Laboratory
Rate I	10.00000 mm/min
Humidity (%)	50.00000
Temperature (deg C)	27.00

Engineering Materials Development Institute

Km 4 Ondo Road P.M.B. 611 Akure 340001

email: director@emdi.gov.ng

Mild steel diam 16mm C1



	Specimen label	Load at Break (Standard) (N)	Maximum Load (N)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (%)
1	Mild Steel samples	13389.36	16686.46	590.16	198.14	473.55	242.95

	Tensile stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)	Extension at Break (Standard) (mm)	Energy at Break (Standard) (J)
1	590.16	2371.80	31.58328	426.46966

	Tensile extension at Break (Standard) (mm)	Area (cm ²)	Diameter (mm)	Length (mm)
1	31.58327	0.28274	6.00000	13.00000

	True strain at Maximum Load (mm/mm)	True stress at Maximum Load (Pa)	Poisson's Ratio (Chord)	Energy at Yield (Zero Slope) (J)
1	1.09239	1759514802.88305	0.28	334.11397

	Extension at Yield (Zero Slope) (mm)	Load at Yield (Zero Slope) (N)
1	25.75828	16686.45889

Medium carbon steel rods

Medium carbon steel rods

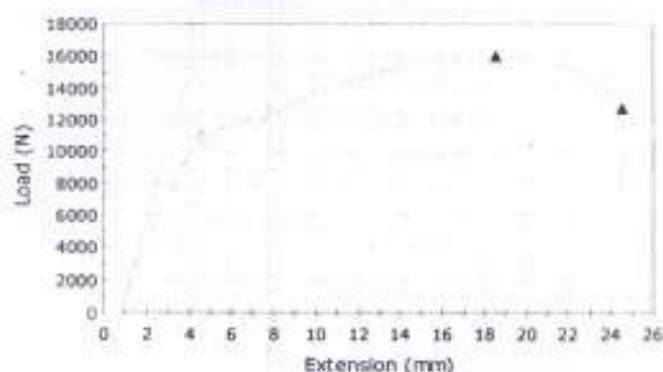
Operator ID	RDO
Company	Engineering Materials Development Institute
Laboratory Name	Mechanical Testing Laboratory
Rate I	10.00000 mm/min
Humidity (%)	50.00000
Temperature (deg C)	27.00

Engineering Materials Development Institute

Km 4 Ondo Road P.M.B. 611 Akure 340001

email: director@emdi.gov.ng

Mild steel diam 16mm C2



	Specimen label	Load at Break (Standard) (N)	Maximum Load (N)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (%)
1	Mild Steel samples	12694.86	16038.85	567.26	142.57	448.99	188.52

	Tensile stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)	Extension at Break (Standard) (mm)	Energy at Break (Standard) (J)
1	567.26	2251.62	24.50812	309.65608

	Tensile extension at Break (Standard) (mm)	Area (cm ²)	Diameter (mm)	Length (mm)
1	24.50812	0.28274	6.00000	13.00000

	True strain at Maximum Load (mm/mm)	True stress at Maximum Load (Pa)	Poisson's Ratio (Chord)	Energy at Yield (Zero Slope) (J)
1	0.88610	1375975842.47435	---	219.09639

	Extension at Yield (Zero Slope) (mm)	Load at Yield (Zero Slope) (N)
1	18.53359	16038.84548

Medium carbon steel rods

Medium carbon steel rods

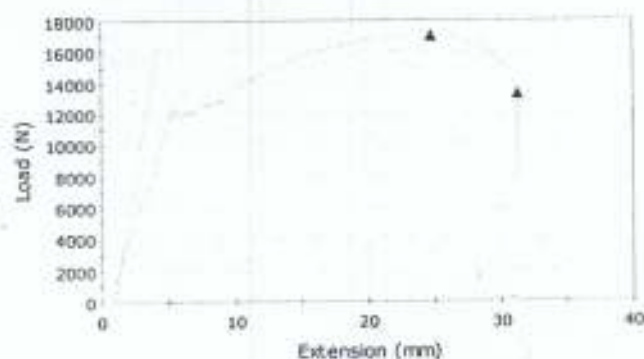
Operator ID	RDO
Company	Engineering Materials Development Institute
Laboratory Name	Mechanical Testing Laboratory
Rate 1	10.00000 mm/min
Humidity (%)	50.00000
Temperature (deg C)	27.00

Engineering Materials Development Institute

Km 4 Ondo Road P.M.B. 611 Akure 340001

email: director@emdi.gov.ng

Mild steel diam 12mm D1



Mild steel diam 12mm D1
1

	Extension at Break (Standard) (mm)	Load at Break (N)	Area (cm ²)	Tensile stress at Break (MPa)	Diameter (mm)	Tensile stress at Yield (MPa)	Tensile strain at Yield (mm/mm)
1	31.31640	17037.19	0.28274	602.57	6.00000	190.77	13.00000
1	Mild Steel samples	13284.28	17037.19	602.57	190.77	469.84	240.90

	Tensile stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)	Extension at Break (Standard) (mm)	Energy at Break (Standard) (J)
1	602.57	2254.66	31.31640	428.26110

	True strain at Maximum Load (mm/mm)	True stress at Maximum Load (Pa)	Poisson's Ratio (Chord)	Energy at Yield (Zero Slope) (J)
1	1.06736	1752073551.98691	---	322.91132

	Extension at Yield (Zero Slope) (mm)	Load at Yield (Zero Slope) (N)
1	24.79984	17037.19497

Medium carbon steel rods

Medium carbon steel rods

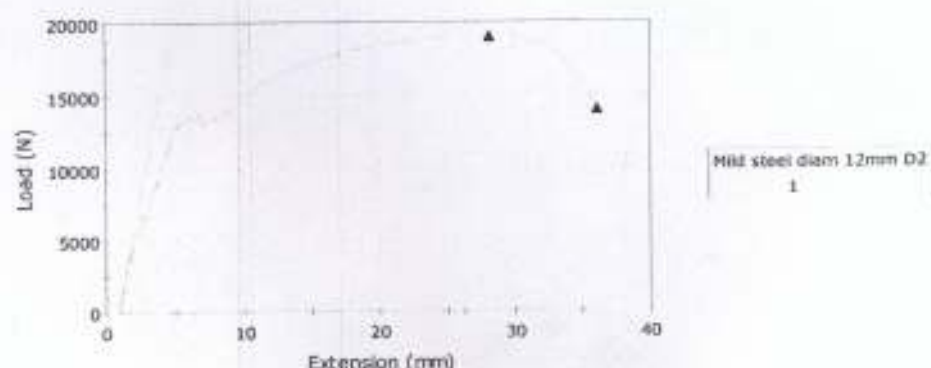
Operator ID	RDO
Company	Engineering Materials Development Institute
Laboratory Name	Mechanical Testing Laboratory
Rate 1	10.00000 mm/min
Humidity (%)	50.00000
Temperature (deg C)	27.00

Engineering Materials Development Institute

Km 4 Ondo Road P.M.B. 611 Akure 340001

email: director@emdi.gov.ng

Mild steel diam 12mm D2



	Specimen label	Load at Break (Standard) (N)	Maximum Load (N)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (%)
1	Mild Steel samples	13991.06	19033.59	673.18	217.31	494.83	277.88

	Tensile stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)	Extension at Break (Standard) (mm)	Energy at Break (Standard) (J)
1	673.18	2316.74	36.12499	562.73291

	Tensile extension at Break (Standard) (mm)	Area (cm ²)	Diameter (mm)	Length (mm)
1	36.12499	0.28274	6.00000	13.00000

	True strain at Maximum Load (mm/mm)	True stress at Maximum Load (Pa)	Poisson's Ratio (Chord)	Energy at Yield (Zero Slope) (J)
1	1.15470	2136037754.18017	---	422.81588

	Extension at Yield (Zero Slope) (mm)	Load at Yield (Zero Slope) (N)
1	28.25000	19033.59145