STATISTICAL ANALYSIS OF THE MECHANICAL PROPERTIES, WEIGHT AND CHEMICAL COMPOSISIONS OF REINFORCING STEEL BARS PRODUCED IN KSA

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A final year project report presented to Prince Mohammad Bin Fahd University
In partial fulfilment of the requirements of the degree of
Bachelor of Engineering

2015

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Abstract

Characteristics of steel reinforcement are as important as that of concrete mixes towards the stability and structural integrity of a project. Present reinforcing steel bars manufactured in Saudi Arabia exhibit a variety of different material properties. The aim of this research is to evaluate and make a statistical analysis on the mechanical and chemical characteristics of steel bars. This data will help identify the quality of steel being produced in accordance with ASTM A615 standard and identify rebars from manufacturers or suppliers which fail to meet the standard. Additionally, a quantitative understanding of the variability of steel properties produced in different industrial zones will assist in the development of strategic planning for each region and Saudi Arabia. Similar research on steel rebars is currently being conducted every five years in countries such as USA and the UK but is a first for Saudi Arabia. This research uses a tensile testing machine to obtain the mechanical properties and a mobile arc spark spectrometer to obtain the chemical properties of the specimen. A thorough investigation of 152 samples is contained within this research from 7 manufacturers along with the results and analysis.

Acknowledgements

We would like to express our deepest gratitude to all those who enabled & guided us for the successful completion of this project report. A special gratitude to our final year project supervisor, Dr. Faramarz Djavanroodi., whose contribution and stimulating suggestions encouraged us to go above and beyond that which was required from the project.

Furthermore, we would also like to acknowledge with much appreciation the crucial role of the staff of SASO – Riyadh, who gave us the required permissions to use their state of the art testing facility in Riyadh for the Mechanical and Chemical Analysis of our collected rebar samples. We would also like to thank SABIC – Jubail as well as Ittefaq Steel – Dammam for their support and contribution towards the testing phase of our project.

Last but not least, many thanks go to the head of the project, Dr. Andi Aziz who invested his full effort & time in guiding the team in achieving the goal.

Acronyms / Symbols

ASTM	American Society for Testing and Materials
EAF	Electric Arc Furnace
DRI	Direct Reduced Iron
REBAR	Reinforcement Bar
GCC	Gulf Cooperation Council
C	Carbon Content
Mo	Molybdenum Content
Cu	Cupper Content
V	Vanadium Content
Mn	Manganese Content
d	Diameter of the Bar

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Chapter 1

Introduction

The production of steel consists of melting iron and scrap after which certain unwanted impurities such as nitrogen, silicon, phosphorus, sulfur and excess carbon are removed from the raw iron, and alloying elements such as manganese, nickel, chromium and vanadium are added to produce different grades (strengths) of steel. The two widely accepted methods to produce steel today are basic oxygen steelmaking, which has liquid pig-iron from the blast furnace and scrap steel as the main feed materials, and electric arc furnace (EAF) steelmaking, which uses scrap steel or direct reduced iron (DRI) as the main feed materials.

Currently in Saudi Arabia – The Electric Arc Furnace method – which uses electrical energy to melt the solid scrap and DRI materials - is widely accepted and implemented to the production of steel.

Once produced in the form of steel billets – the Steel can be used for the production of Rebars. Rebar- Also known as Reinforcing Bar, is a steel bar used as a tension load bearing device in reinforced concrete and reinforced masonry structures. Concrete is very resilient to compressive forces but fails under tension. For this purpose – Rebars are used to absorb the tensile forces and protect the structure against failure. Rebar's surface is often patterned with ribs and fins to form a better bond with the concrete.

1.1 Motivation

Characterizations of steel reinforcement are as important as that of concrete ingredients towards the stability and structural integrity of a project. Present reinforcing steel bar manufactured in Saudi Arabia exhibits a variety of different material properties. The aim of this research work is to evaluate and make a statistical analysis on the mechanical and chemical characteristics of steel bars. The data is derived experimentally according to ASTM A615. This is in order to propose a new ranking scheme for the quality of rebar's manufactured in different industrial zone in Saudi Arabia (Dammam, Riyadh, Jeddah etc.).

1.2 Objectives and Scope

For this research – a very large dataset sample is required to be taken from all rebar manufacturers in KSA. From the results a quantitative understanding of the variability of steel properties produced in different industrial zones will assist in the development of proper quality assurance strategic planning for each region and Saudi Arabia. The uncertainties in raw material input and fabrication approach which will differ substantially from one manufacturer to another can then be categorized statistically in the quality of rebars produced. The statistical analysis of the data can then be used to indicate any short comings regarding the process or the raw material choice for each industrial zone.

Chapter 2

Literature Review

Steel is one of the basic building blocks of the modern world. Automobiles, appliances, bridges, oil pipelines, and buildings, all are made with steel. While steel manufacturing has existed for centuries, the process for making steel continues to evolve. Establishments in this industry produce steel by melting iron ore, scrap metal, and other additives in furnaces. Conventional reinforced concrete is a composite material of steel bars embedded in a hardened concrete matrix.

The high cost of reinforced concrete coupled with a bid to protect the environment from non-biodegradable wastes such as metals and concrete debris has led to worldwide research into recycling these waste materials during the past two decades. The challenge this offers to structural engineers is whether the performance of steel bars produced by re-cycling from scrap metal meets the engineering and safety specifications of the code of practice for structural applications [1–8].

There have been a number of statistical studies dealing specifically with the variability of the mechanical properties of reinforcing steel [9-12]. In these studies, variations in yield and tensile strengths were examined. These variations were believed to be caused by variation in the rolling practices and quality control measures used by different manufacturers, as well as possible variations in cross-sectional area, steel strength, and rate of loading.

To develop statistical descriptors for the mechanical properties of reinforcing steel, Mirza and MacGregor [9] studied the results of about 4000 tensile tests. The sample included rebars having wide range of diameters (9.5-57.3mm) and two grades of steel (yield strength = 276 MPa or 414 MPa). The means and standard deviations of the mill test yield strengths were found to be 337 MPa and 36.1 MPa for Grade 276 steel, and 490 MPa and 45.6 MPa for Grade 414 steel, respectively. Beta distributions were used to represent the probability density function of these sets of data.

Joshi and Ranganathan [13] analyzed statistical data on yield strength and modulus of elasticity of reinforcing steel bars from rolling mills and building sites. At 5% level of significance, it was found that the normal distribution can best represent the data on yield strength, while the lognormal distribution can fit well the data on modulus of elasticity.

In a study on steel reinforcing bars used in Turkey, Akyz and Uyan [14] agreed with the requirements of Turkish Steel Rebar Specification Standard TS-708. In Saudi Arabia, Arafah [15] used an experimental program to develop probabilistic models for compressive strength of concrete and yield strength of reinforcing steel produced in the country. A total of 955 concrete samples and 434 samples of steel bars were randomly collected from construction sites. The results of the experimental testing indicated that ready mixed concrete can be modeled by normal distribution; whereas site mixed concrete is better represented by log-normal distribution.

Variations in the yield strength of reinforcing steel are modeled by normal distribution, with a bias factor.

Recently, Galasso et al. [16] carried out statistical analysis of reinforcing steel properties based on about 200 test data. The data included a wide range of reinforcing steel bars with diameter between 12 and 26 mm made in Italy. The tests results were analyzed to determine the appropriate cumulative distribution function for yield and ultimate strengths. Comparison with previous tests confirmed that there is an improvement in quality and ductility of materials and a reduction in strength variability for the considered steel.

Saudi Arabia's steel demand has made the country one of the largest consumer in the GCC region. The country also accounts for significant number of construction activities in the Middle-East region. Over the past decade, steel consumption in the Kingdom has increased considerably buoyed by construction boom, growing investment in the real estate sector and rapid infrastructure developments. In addition, the steel industry has witnessed tremendous growth in terms of production, as various players are expanding their production capacities to meet the soaring steel demand [17].

The purpose of this study is as stated above to propose a unified approach to rebar making and standardize the quality assurance in KSA. Moreover, assessing the quality of rebars manufactured in KSA within the last 5 years can and will help to standardize the quality of manufacturing and producing of rebars in the future. The tasks to deliver these objectives will cover mechanical testing of rebars produced from all the steel manufacturing plants in the KSA and to derive and investigate the relevant parameters related to the quality of reinforcing bars.

Furthermore, statistical analysis of the rebar properties will need to be conducted for acceptably large numbers of data to identify the variability of the mechanical properties, weight and chemical composition of steel reinforcing bars produced in the KSA under ASTM A 615. Expressions can then be developed to represent the probability distribution functions for yield, tensile strengths, weight and chemical composition. The results should help the long term financial stability and mechanical viability and structural safety for this sector in KSA.

Chapter 3

Theory

3.1 – Statistical Analysis

In this research we are going to use a simple statistics approach in order to analyse and interpret our results. Furthermore, we got the variations, median, average and standard deviation between different areas and different manufacturers. We used this approach to see the correlation between mechanical and chemical properties of the rebars manufactured in Saudi Arabia. In relation to to the standards ASTM A615, we can compare and analyse the shortcomings whether in the manufacturing process or the input of raw material before manufacturing.

Moreover, obtaining such results will enable us to tackle and assess each property of the rebars such as strength, ductility and hardness. As a consequence we can predict the future shortcomings in manufacturing of rebars and improve overall quality of the product.

Chapter 4

Experimental Procedure

4.1 Materials

For this research – **ASTM A615-60 grade steel** is analyzed which is a structural billet steel for structural applications. A615-60 grade is a material grade and designation defined in ASTM A615 standard. ASTM A615 is an international material standard for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement & strengthening application.

4.1.1- Dimensional Characteristics of A615-60 Grade Steels:

The applicable diameter for this A615-60 GRADE material as defined in the ASTM A615 ranges to 22.2-28.7 mm. The perimeter is usually around 69.8-90 mm. The cross sectional area is about 387-645 mm2.

4.1.2- The Chemical Composition of A615-60 Grade Steels:

ASTM A615 defines the chemical composition of A615-60 Grade steels as:

Maximum percentage of **Phosphorous** (P) is identified by the standard i.e. **0.060**

Maximum percentage of **Carbon** (C) is identified by the standard i.e **0.33**

Maximum percentage of **Sulphur** (S) is identified by the standard i.e **0.052**

Remaining is **Iron** (Fe) percentage and with few other alloys and negligible impurities.

4.1.3- Mechanical Properties of A615-60 Grade Steels:

The tensile strength of the A615-60 Grade Steels is expressed in Newton per millimeters and it must be at-least 620 N/mm2 (MPa). The yield strength is minimum 413 N/mm2 (MPa). The minimum percentage ranges for elongation is 9% thicknesses. 180 degree bends on 3.5 diameters.

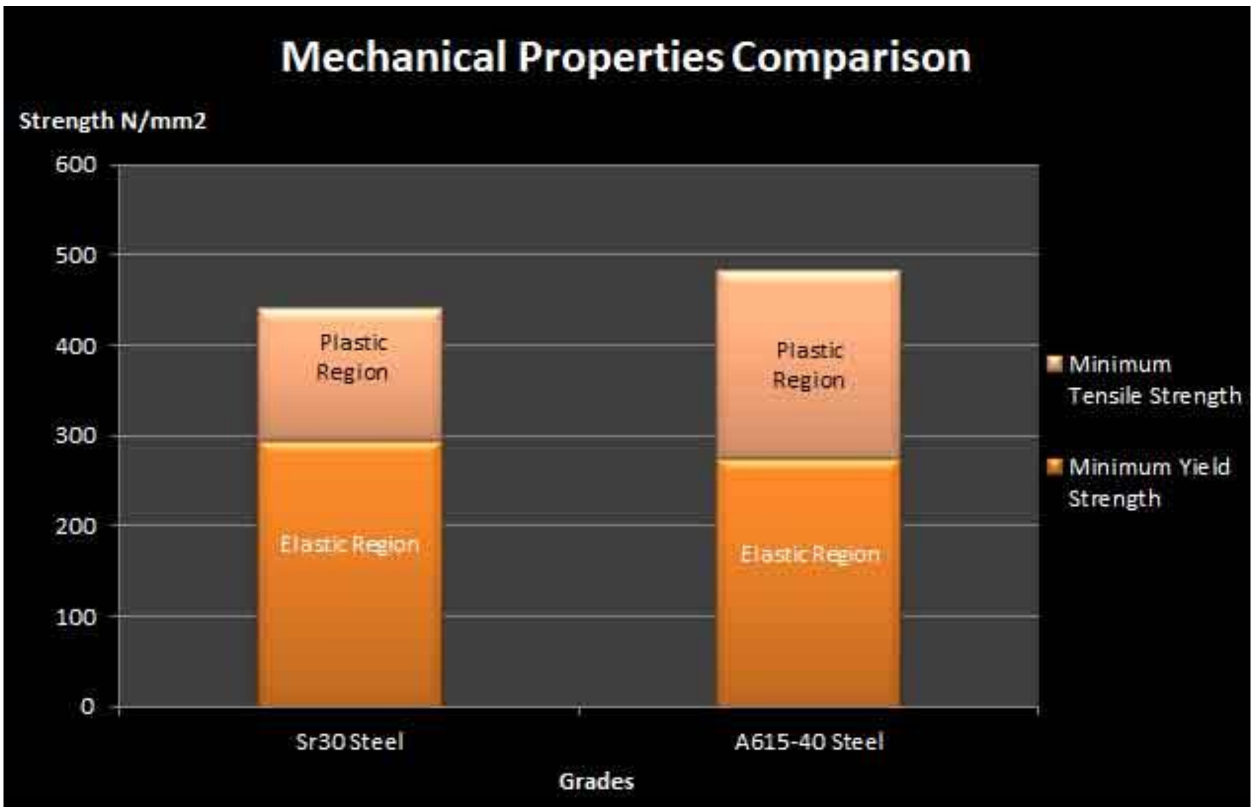

Fig 4.1.3a - Comparison between ASTM A615-60 Grades vs. ASTM A615- 40 Grades

ASTM A615 Grade 60 rebar is commonly utilized as a tensioning stratagem in reinforced concrete and strengthened building materials structures holding the concrete in compression. It is typically used in Construction, Bridge Building, and Road Building etc.

4.2 Testing

4.2.1 - Mechanical Testing (Tensile Test)

In tensile test, we secure a reinforcing steel rebar between two grips; we then apply a tension uniaxial load to the rebar, the graph produces by the tensile test machine is the stress-strain diagram. The steel rebar will go through a numerous number of phases during the test. The first phase is the elastic deformation, the entire test specimen is elongated and in case the load is released the specimen will return back to its original shape and length. After that the plastic deformation accurse, the plastic deformation is a phase where if we released the load, the material will get hardened because the graph will show us a line parallel to the elastic deformation line but it will be shifted to the right, this means that the material will have higher strength but less ductility. After that the necking of the material starts, only a local deformation will occur in this phase, which means that only a small region of the test rebar will start decreasing in diameter until the specimen breaks. The engineering point of view for the

Figure 4.2.1 a – Tensile testing Machine

necking phase will show us that the materials stress will start decreasing at the necking point, this is just happening because in the calculation for the stress we are not calculating the exact decreasing in diameter which is showing us that the stress is being reduced, but what is actually happening is that the specimens diameter is being decreased while the load is increasing, which will then show us higher stress results, this is the difference between the real stress-strain curve and an engineering stress-strain curve. The Engineering Stress-Strain Curve is shown in the Fig (x) below

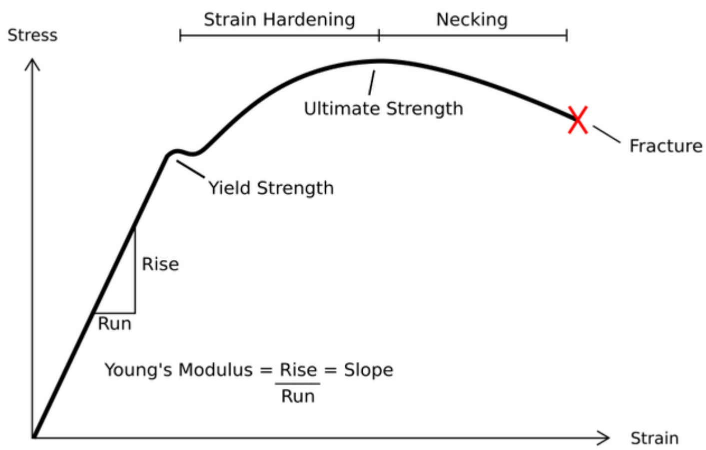

Fig 4.2.1 b – Stress vs Strain graph of Steel

1) METTLER TOLEDO BBA236

   Is the weighing machine, it was used to find the weight in Kilograms for all the test samples

2) Tape Measure

   A normal tape was used to find the length in meters for all the test specimens

3) INSTRON **5982**

   INSTRON 5982 was used to do the tensile test; this was used for samples for diameters 6mm to 10mm. This was due to its loading capacity being capped at 100 KN.

4) INSTRON **1500 KPX-J3D-L3**

   This machine was used to do the tensile test for samples up to 32mm. INSTRON **1500 KPX-J3D-L3** can handle loads up to 1500 KN.

4.2.2-Chemical Testing:

Figure 4.2.2 a – Grinding Operation prior Chemical Testing

To gain the chemical components of the steel samples, a spectrometer is used; the spectrometer test is also called a spark test. The test specimen is prepared and put on a small stand for the test, spark is released from the stand to the bottom of the steel sample to burn it, after that the machine absorbs all the evaporated gas coming out from the test sample and puts it through a spectrometer to check the wave's length and frequently, from these data it gains most the known steel chemical components. This test requires a freshly polished steel sample; otherwise just the touch of a finger could add some small particles to the sample which will yield to some inaccurate data.

Testing Equipment

1) FOUNDRY-MASTER **Xline**

   This is the Spectrometer test (Spark Test) machine; it was used to find the chemical composition of the test specimens. This machine can give results for us to 27 different chemical components.

Figure 4.2.2 b – Foundry Master X-line

Chapter 5

Results & Discussion

5.1 Results

5.1.1- Tensile Results

Saudi Arabia has about 29 different steel manufacturers; we were able to collect 158 samples from 7 different manufacturers. 134 samples of these were tested under uniaxial loading to produce the Stress-Strain graph.

5.1.2- List of Different Manufacturers

Manufacturers in Saudi that helped us collect the samples. Hadeed samples were collected from a Supplier called Heat Establishment and Bawan Steel.

	Company	Capacity	Location
1	Hill Metals(1)	300,000	Jeddah
2	Al-Raki Steel (Mukarish)	300,000	Rabigh
3	JAFCO	300,000	Dammam
4	Mahmood Abdullah	205,000	Dammam
5	Watania Steel (National Steel)(1)	200,000	Riyadh
6	Wofoor Industrial Company(2)	200,000	Kharj
7	Al-Sa'ad	146,000	Madinah
8	Aslak	116,000	Riyadh
9	Riyadh Steel	100,000	Riyadh
10	Taybah Metals (Taiba Gulf Steel factory)(1)	100,000	Riyadh
11	Al-Usaimi Steel(2)	60,000	Dammam
12	Al-Bargan	40,000	Riyadh
13	Al-Sarqia Steel	35,000	Hassa
14	Al-Salamah factory	30,000	Riyadh
15	Basaak Metal Factory	30,000	Riyadh
16	Darfalah Al-Arabian factory	22,000	Riyadh
17	Muteb Said Factory	20,000	Madinah
18	Jeddah Steel Factory	20,000	Jeddah
19	Soroh Al-Assemah Steel	12,000	Riyadh

20	**Bas Factory**	**12,000**	**Jeddah**
21	**Omar Al-Harbi**	**7,500**	**Jeddah**
22	**AL YAMAMAH**	700,000	
23	**AL ITTEFAQ STEEL**	**NA**	**Makkah**
24	**AL ITTEFAQ STEEL**	2,800,000	**Dammam**
25	**RAJHI STEEL**	640,000	**Kharj**
26	**RAJHI STEEL**	1,180,000	**Jeddah**
27	**SOLB STEEL COMPANY**	500,000	**Jizan**
28	**SABIC GROUP KSA HADEED**	NA	**Al-Jubail**
29	**Universal Factory**	**6,000**	**Jeddah**

Table 5.1.2a – List of Steel Manufacturers

5.1.3- Tensile Test Results

Below is a Graph that shows all the tensile test results for the 134 samples that were tested in the making of this paper.

Sample Identification	Sample Diameter (mm)	Nominal Wight (kg/m)	Yield Strength (Mpa)	Tensile Strength (Mpa)	Elongation (%)
1) US-06-1	6	0.219	541	614	9.5
2) SA-8-1	8	-5.82	473	690	4
3) IT-10-1	10	0.608	594.55	674.46	11
4) IT-10-2	10	0.602	605.1	664.65	13
5) IT-10-3	10	0.608	590.61	668.51	10
6) SA-10-1	10	-2.26	408	540	15
7) SA-10-2	10	-3.24	403	534	15
8) YS-10-1	10	0.601	582.24	687.2	11
9) YS-10-2	10	0.593	596.76	696.53	11
10) YS-10-3	10	0.594	596.89	695.34	11
11) US-12-1	12	0.872	498.81	732.83	15
12) US-12-2	12	0.872	499.66	733.19	17
13) US-12-3	12	0.876	457.8	693.42	19
14) YS-12-1	12	0.856	574.54	677.9	14
15) YS-12-2	12	0.858	575.14	676.13	13
16) YS-12-3	12	0.852	573.13	674.3	14
17) SA-12-1	12	-4.28	580	667	12
18) SA-12-2	12	-4.58	583	671	11.5

19) BA-12-1	**12**	**-2.62**	**550**	**643**	**14**
20) BA-12-2	**12**	**-4.39**	**539**	**633**	**14**
21) RJ-12-1	**12**	**0.861**	**444.2**	**679.01**	**18**
22) RJ-12-2	**12**	**0.861**	**444.53**	**678.91**	**18**
23) RJ-12-3	**12**	**0.864**	**447.87**	**680.06**	**18**
24) WA-12-1	**12**	**0.862**	**585.23**	**661.54**	**10**
25) WA-12-2	**12**	**0.852**	**570.6**	**663.52**	**12**
26) WA-12-3	**12**	**0.848**	**578.94**	**668.33**	**12**
27) TA-12-1	**12**	**0.898**	**549.57**	**671.81**	**13**
28) TA-12-2	**12**	**0.9**	**529.47**	**655.93**	**13**
29) TA-12-3	**12**	**0.9**	**550.72**	**676.3**	**13**
30) IT-12-1	**12**	**0.856**	**583.76**	**699.92**	**14**
31) IT-12-2	**12**	**0.868**	**615.06**	**693.94**	**11**
32) IT-12-3	**12**	**0.868**	**620.31**	**696.85**	**13**
33) RA-12-1	**12**	**0.86**	**458**	**681**	**13.0**
34) RA-12-2	**12**	**0.856**	**456**	**687**	**12.5**
35) RA-12-3	**12**	**0.867**	**462**	**689**	**13.5**
36) US-12-2	**12**	**0.954**	**489**	**679**	**12.0**
37) IT-12-1	**12**	**0.865**	**620**	**694**	**13.0**
38) HA-12-1	**12**	**NA**	**575**	**664**	**13.5**
39) HA-12-2	**12**	**NA**	**567**	**663**	**13.3**
40) HA-12-3	**12**	**NA**	**584**	**682**	**14.3**
41) JA-14-1	**14**	**1.126**	**510**	**642**	**15.0**

42) JA-14-2	**14**	**1.127**	**524**	**639**	**14.0**
43) US-14-2	**14**	**1.292**	**420**	**661**	**14.0**
44) HA-14-1	**14**	**NA**	**587**	**718**	**14**
45) HA-14-2	**14**	**NA**	**573**	**695**	**13.5**
46) HA-14-3	**14**	**NA**	**560**	**687**	**13.8**
47) SA-14-1	**14**	**-2.31**	**546**	**686**	**15**
48) SA-14-1	**14**	**-3.47**	**528**	**663**	**14**
49) BA-14-1	**14**	**-5.87**	**532**	**642**	**15.5**
50) BA-14-1	**14**	**-6.35**	**537**	**641**	**17**
51) US-14-1	**14**	**1.191**	**457.26**	**678.32**	**18**
52) US-14-2	**14**	**1.189**	**462.96**	**679.94**	**18**
53) US-14-3	**14**	**1.196**	**460.01**	**678.77**	**17**
54) WA-14-1	**14**	**1.165**	**530.35**	**643.6**	**14**
55) WA-14-2	**14**	**1.169**	**524.32**	**639.95**	**16**
56) WA-14-3	**14**	**1.169**	**523.31**	**640.01**	**14**
57) YA-14-1	**14**	**1.166**	**607.84**	**696.18**	**13**
58) YA-14-2	**14**	**1.167**	**597.35**	**693.91**	**14**
59) YA-14-3	**14**	**1.166**	**605.37**	**697.42**	**11**
60) TA-14-1	**14**	**1.189**	**529.92**	**698.26**	**14**
61) TA-14-2	**14**	**1.188**	**538.55**	**708.14**	**14**
62) TA-14-3	**14**	**1.188**	**543.55**	**708.07**	**12**
63) IT-14-1	**14**	**1.145**	**575.41**	**674.68**	**14**
64) IT-14-2	**14**	**1.148**	**572.86**	**676.37**	**14**

65) IT-14-3	**14**	**1.145**	**570.1**	**673.84**	**14**
66) US-16-1	**16**	**1.729**	**444**	**689**	**14.5**
67) US-16-2	**16**	**1.681**	**450**	**698**	**13.5**
68) US-14-2	**14**	**1.292**	**420**	**661**	**14.0**
69) HA-16-1	**16**	**NA**	**612**	**718**	**15**
70) HA-16-2	**16**	**NA**	**582**	**705**	**14.5**
71) HA-16-3	**16**	**NA**	**588**	**706**	**15**
72) JA-16-1	**16**	**1.495**	**526**	**677**	**14.5**
73) JA-16-2	**16**	**1.461**	**540**	**669**	**14.5**
74) RA-16-1	**16**	**1.536**	**571**	**677**	**13.5**
75) RA-16-2	**16**	**1.532**	**579**	**677**	**14.0**
76) RA-16-3	**16**	**1.535**	**575**	**676**	**14.5**
77) IT-16-1	**16**	**1.552**	**595.13**	**673.32**	**14**
78) IT-16-2	**16**	**1.573**	**615.74**	**698.69**	**14**
79) IT-16-3	**16**	**1.566**	**614.92**	**694.91**	**14**
80) WA-16-1	**16**	**1.515**	**541.72**	**650.04**	**12**
81) WA-16-2	**16**	**1.529**	**518.98**	**652.58**	**13**
82) WA-16-3	**16**	**1.534**	**535.82**	**653.43**	**13**
83) TA-16-1	**16**	**1.566**	**475.03**	**628.56**	**15**
84) TA-16-2	**16**	**1.567**	**477.63**	**629.95**	**17**
85) TA-16-3	**16**	**1.535**	**485.13**	**611.15**	**15**
86) US-16-1	**16**	**1.543**	**447.81**	**694.36**	**15**
87) US-16-2	**16**	**1.553**	**452.68**	**695.9**	**18**
88) US-16-3	**16**	**1.549**	**449.28**	**693.71**	**19**

89) SA-16-1	**16**	**-5.7**	**538**	**653**	**13.5**
90) SA-16-2	**16**	**-0.475**	**547**	**660**	**15**
91) BA-16-1	**16**	**-4.57**	**538**	**671**	**14**
92) BA-16-2	**16**	**-5.1**	**537**	**667**	**17**
93) Hadeed	**16**	**-4.36**	**544**	**653**	**11.5**
94) Hadeed	**16**	**-5.1**	**524**	**638**	**12**
95) YA-16-1	**16**	**1.508**	**575.12**	**674.31**	**15**
96) YA-16-2	**16**	**1.521**	**574.87**	**674.36**	**15**
97) YA-16-3	**16**	**1.547**	**600.66**	**693.21**	**16**
98) YA-18-1	**18**	**1.926**	**590.33**	**690.65**	**16**
99) YA-18-2	**18**	**1.926**	**594.37**	**695.76**	**15**
100) YA-18-3	**18**	**1.927**	**589.76**	**692.5**	**17**
101)WA-18-1	**18**	**1.926**	**560.06**	**683.14**	**14**
102)WA-18-2	**18**	**1.917**	**525.93**	**671.35**	**15**
103)WA-18-3	**18**	**1.93**	**542.82**	**670.8**	**13**
104)RJ-18-1	**18**	**1.904**	**422.12**	**687.07**	**17**
105)RJ-18-2	**18**	**1.901**	**420.86**	**685.58**	**19**
106)RJ-18-3	**18**	**1.912**	**420.73**	**690.3**	**16**
107)IT-18-1	**18**	**1.129**	**566.44**	**669.15**	**15**
108)IT-18-2	**18**	**1.883**	**569.67**	**671.86**	**15**
109)IT-18-3	**18**	**1.898**	**569.05**	**672.69**	**15**
110) HA-20-1	**20**	**NA**	**581**	**710**	**17.3**
111) HA-20-2	**20**	**NA**	**579**	**703**	**17.3**

112) HA-20-3	**20**	**NA**	**581**	**710**	**17.3**
113) JA-20-1	**20**	**2.291**	**501**	**642**	**14.5**
114) SA-20-1	**20**	**-3.81**	**549**	**680**	**17**
115) SA-20-2	**20**	**-4.5**	**547**	**675**	**16.5**
116) IT-20-3	**20**	**2.385**	**586**	**701**	**15.0**
117) YA-20-1	**20**	**2.373**	**568.95**	**669.72**	**17**
118) YA-20-2	**20**	**2.367**	**569.74**	**674.75**	**17**
119) YA-20-3	**20**	**2.373**	**569**	**669.05**	**17**
120) YA-25-1	**25**	**3.685**	**573.93**	**668.62**	**17**
121) YA-25-2	**25**	**3.676**	**572.88**	**667.7**	**17**
122) YA-25-3	**25**	**3.683**	**575.69**	**669.03**	**17**
123) JA-32-2	**32**	**5.82**	**495**	**627**	**16.5**
124) JA-25-1	**25**	**3.495**	**516**	**661**	**18.0**
125) JA-25-2	**25**	**3.431**	**519**	**669**	**15.0**
126) IT-25-1	**25**	**3.775**	**591**	**702**	**16.0**
127) IT-25-3	**25**	**3.873**	**591**	**702**	**16.5**
128) HA-25-1	**25**	**NA**	**498**	**648**	**17.8**
129) HA-25-2	**25**	**NA**	**508**	**672**	**16**
130) HA-25-3	**25**	**NA**	**519**	**675**	**17.8**
131) SA-25-1	**25**	**-3.32**	**516**	**675**	**17.5**
132) SA-25-2	**25**	**-3.65**	**506**	**667**	**17.5**
133) BA-25-1	**25**	**-4.06**	**562**	**674**	**16**
134) BA-25-2	**25**	**-3.17**	**521**	**671**	**17.5**

Table 5.1.3a – Tensile test results

5.1.4 – Tensile test Discussion

Yield strength

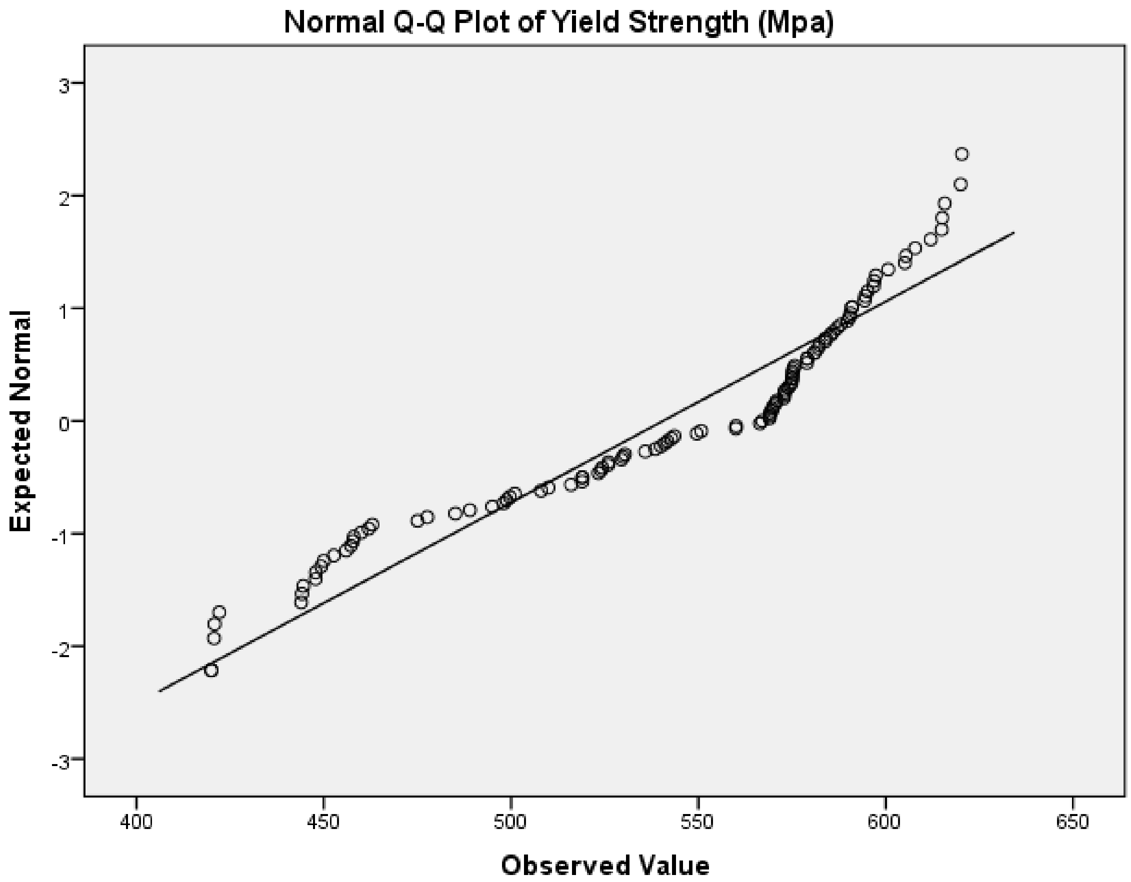

Figure 5.1.4-a: Distribution Graph of Yield Strength vs Normal Line

Both normality tests indicate the data is not normal that is also reflected in the histogram and Q-Q plot. Moreover, it shows that yield strength among samples is not normally distributed which indicates variability among manufacturers or manufacturing processes. However, Distribution of Yield Strength of bars 10 and 14 can be considered normal, but not other sizes.

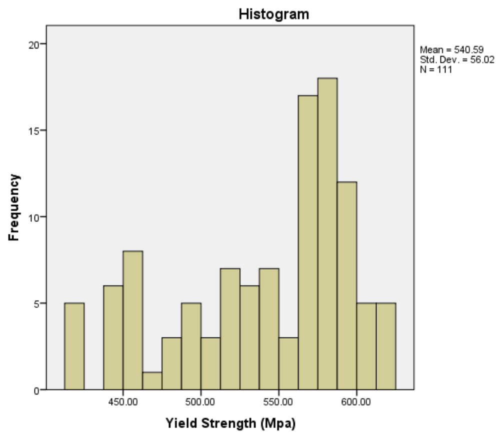

Figure 5.1.4-b: Histogram Yield Strength

Tensile strength

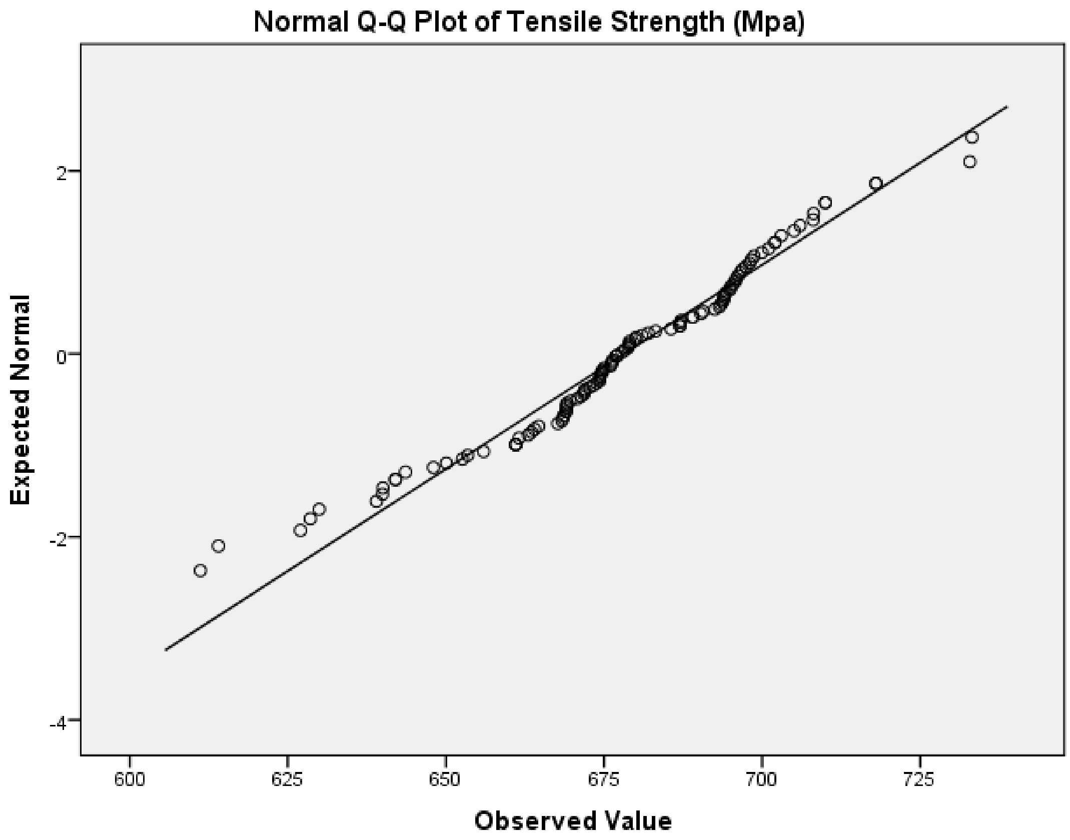

Figure 5.1.4-c: Distribution Graph of Tensile Strength vs Normal Line

Tensile strength is not normally distributed among samples, which means there are fluctuations in the manufacturing process between manufacturers. However, only bar 12 diameter is normal.

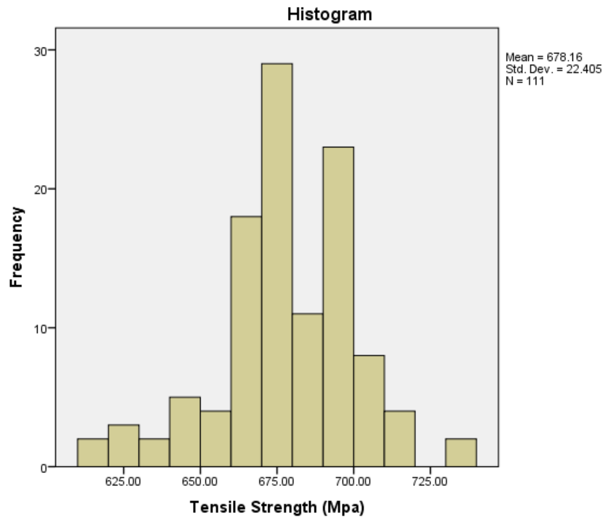

Figure 5.1.4-d: Histogram Tensile Strength

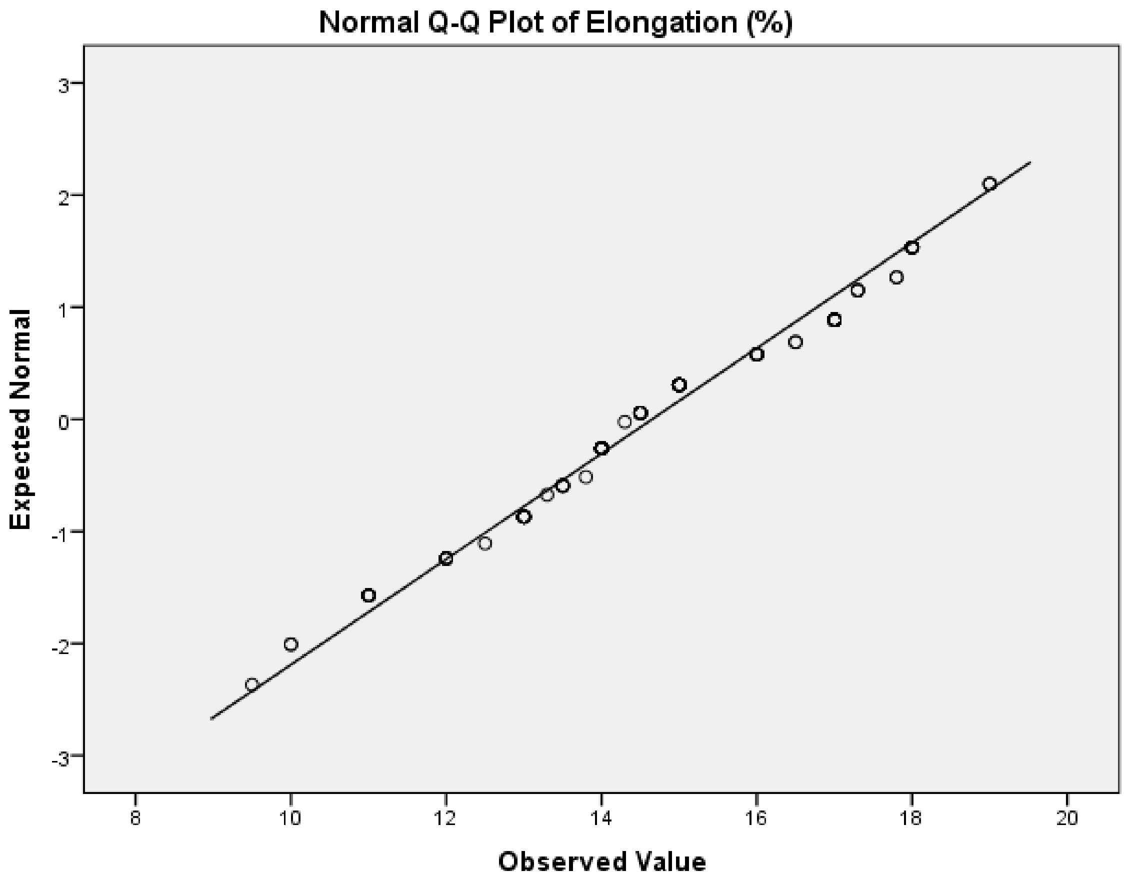

Figure 5.1.4-e: Distribution Graph of % elongation vs Normal Line

From the Q-Q graph and the histogram the samples are not normally distributed. However, only size 18 and 25 are normal.

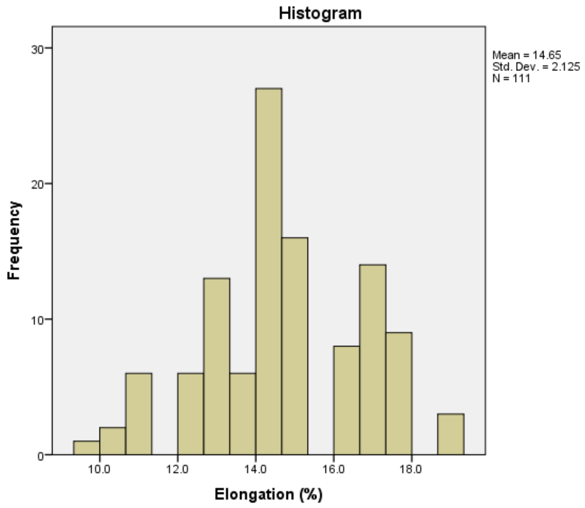

Figure 5.1.4-f: Histogram % Elongation

5.2.1- Chemical Tests

The Spector meter test that we did in SASO was able to acquire the percentages of 27 different chemical components, while the chemical test results that we got from Hadeed-Sabic Group provide 29 different components. In our research we will be focusing on 3 components only because that's exactly what ASTM A615 is asking for, ASTM A615 sets a max percentage limit for carbon to be 0.33%, a max sulfur percentage of 0.053% and a phosphorus percentage less than 0.06%.

5.2.2) List of Different Manufacturers

Manufacturers in Saudi Arabia that helped us collect the chemical testing samples. Hadeed samples were collected from a Supplier called Heat Establishment:

	Company	Capacity (Ton)	Location
1	Hill Metals(1)	300,000	Jeddah
2	Al-Raki Steel (Mukarish)	300,000	Rabigh
3	JAFCO	300,000	Dammam
4	Mahmood Abdullah	205,000	Dammam
5	Watania Steel (National Steel)(1)	200,000	Riyadh
6	Wofoor Industrial Company(2)	200,000	Kharj
7	Al-Sa'ad	146,000	Madinah
8	Aslak	116,000	Riyadh
9	Riyadh Steel	100,000	Riyadh
10	Taybah Metals (Taiba Gulf Steel factory)(1)	100,000	Riyadh
11	Al-Usaimi Steel(2)	60,000	Dammam
12	Al-Bargan	40,000	Riyadh
13	Al-Sarqia Steel	35,000	Hassa
14	Al-Salamah factory	30,000	Riyadh
15	Basaak Metal Factory	30,000	Riyadh
16	Darfalah Al-Arabian factory	22,000	Riyadh
17	Muteb Said Factory	20,000	Madinah
18	Jeddah Steel Factory	20,000	Jeddah

19	Soroh Al-Assemah Steel	12,000	Riyadh
20	Bas Factory	12,000	Jeddah
21	Omar Al-Harbi	7,500	Jeddah
22	AL YAMAMAH	700,000	
23	AL ITTEFAQ STEEL	NA	Makkah
24	AL ITTEFAQ STEEL	2,800,000	Dammam
25	RAJHI STEEL	640,000	Kharj
26	RAJHI STEEL	1,180,000	Jeddah
27	SOLB STEEL COMPANY	500,000	Jizan
28	SABIC GROUP KSA HADEED	NA	Al-Jubail
29	Universal Factory	6,000	Jeddah

Table 5.2.2a – List of Steel Manufacturers

5.2.3- Chemical Test Results

Below is a Table that shows all the chemical test results for the 71 samples that were tested in the making of this paper.

Sample Id.	Size(mm)	C	P	S	Cu	Cr	Mo	Ni	V	Si
1) US-06-1	6	0.189	0.018	0.012	0.08	0.06	0.01	0.03	0	0.21
2) US-8-2	8	0.0982	0.031	0.021	0.01	0.39	0	0.14	0.0069	0.2
3) US-8-1	8	0.114	0.025	0.017	0.01	0.37	0	0.01	0.84	0.186
4) HA-12-1	12	0.19	0.015	0.007	0.02	0.01	0.01	0.02	0.001	0.22
5) HA-12-3	12	0.19	0.009	0.006	0.05	0.03	0.01	0.03	0.002	0.22
6) HA-12-2	12	0.19	0.01	0.005	0.03	0.01	0.01	0.02	0	0.22
7) RA-12-1	12	0.34	0.011	0.009	0	0.02	0.01	0.01	0.002	0.264
8) RA-12-2	12	0.339	0.009	0.008	0	0.01	0.01	0.01	0.001	0.266
9) RA-12-3	12	0.338	0.01	0.009	0	0.02	0.01	0.01	0.002	0.27
10) US-12-2	12	0.322	0.016	0.008	0.1	0.11	0.02	0.06	0.011	0.266
11) US-12-3	12	0.318	0.017	0.008	0.09	0.11	0.02	0.06	0.011	0.262
12) IT-12-1	12	0.21	0.01	0.006	0.05	0.02	0.01	0.02	0	0.236
13) HA-14-1	14	0.32	0.011	0.015	0.05	0.01	0	0.02	0.003	0.22
14) UA-14-1	14	0.228	0.011	0.005	0.07	0.09	0	0.05	0.0039	0.276
15) JA-14-1	14	0.248	0.195	0.195	0.13	0.11	0.01	0.08	0.0114	0.24
16) WA-14-1	14	0.254E	0.211	0.032	0.13	0.08	0	0.04	0.0053	0.295
17) SA-14-1	14	0.306	0.097	0.012	0.12	0.02	0	0.04	0.0047	0.281

18) IT-14-1	**14**	**0.268**	**0.011**	**0.011**	**0.06**	**0.03**	**0**	**0.02**	**0.0046**	**0.217**
19) US-14-2	**14**	**0.313**	**0.018**	**0.024**	**0.3**	**0.08**	**0.02**	**0.09**	**0.0046**	**0.236**
20) TA-14-1	**14**	**0.312**	**0.021**	**0.018**	**0.1**	**0.11**	**0**	**0.04**	**0.0123**	**0.328**
21) HA-14-2	**14**	**0.3**	**0.007**	**0.013**	**0.06**	**0.01**	**0**	**0.02**	**0.003**	**0.22**
22) HA-14-3	**14**	**0.31**	**0.007**	**0.011**	**0.05**	**0.01**	**0**	**0.02**	**0.003**	**0.22**
23) US-14-2	**14**	**0.319**	**0.009**	**0.016**	**0.25**	**0.08**	**0.03**	**0.09**	**0.001**	**0.226**
24) JA-14-1	**14**	**0.24**	**0.019**	**0.013**	**0.01**	**0.12**	**0.02**	**0.07**	**0.005**	**0.182**
25) JA-14-2	**14**	**0.229**	**0.013**	**0.009**	**0.09**	**0.12**	**0.02**	**0.07**	**0.009**	**0.205**
26) TA-16-1	**16**	**0.296**	**0.024**	**0.023**	**0.1**	**0.18**	**0**	**0.04**	**0.0065**	**0.378**
27) US-16-2	**16**	**0.338**	**0.024**	**0.018**	**0.11**	**0.14**	**0.01**	**0.05**	**0.0083**	**0.322**
28) RA-16-3	**16**	**0.212**	**0.008**	**0.023**	**0.24**	**0.05**	**0**	**0.08**	**0.0031**	**0.232**
29) IT-16-1	**16**	**0.201**	**0.018**	**0.013**	**0.09**	**0.06**	**0**	**0.03**	**0.0053**	**0.247**
30) WA-16-1	**16**	**0.237**	**0.017**	**0.017**	**0.12**	**0.08**	**0.01**	**0.05**	**0.0068**	**0.188**
31) JA-16-2	**16**	**0.269**	**0.022**	**0.012**	**0.09**	**0.08**	**0.01**	**0.05**	**0.0095**	**0.285**
32) YA-16-1	**16**	**0.243**	**0.011**	**0.007**	**0.05**	**0.06**	**0**	**0.04**	**0.0061**	**0.29**
33) SA-16-1	**16**	**0.279**	**0.014**	**0.007**	**0.03**	**0.02**	**0**	**0.03**	**0.0068**	**0.265**
34) JA-16-1	**16**	**0.264**	**0.016**	**0.009**	**0.07**	**0.08**	**0.02**	**0.04**	**0.005**	**0.231**
35) JA-16-2	**16**	**0.26**	**0.019**	**0.011**	**0.08**	**0.08**	**0.02**	**0.04**	**0.004**	**0.218**
36) RA-16-1	**16**	**0.215**	**0.004**	**0.022**	**0.23**	**0.05**	**0.01**	**0.07**	**0**	**0.204**
37) RA-16-2	**16**	**0.212**	**0.005**	**0.028**	**0.23**	**0.05**	**0.01**	**0.07**	**0**	**0.193**
38) RA-16-3	**16**	**0.214**	**0.005**	**0.027**	**0.23**	**0.05**	**0.01**	**0.07**	**0**	**0.2**

39) HA-16-1	**16**	**0.3**	**0.008**	**0.017**	**0.03**	**0.02**	**0**	**0.02**	**0.005**	**0.23**
40) HA-16-2	**16**	**0.3**	**0.007**	**0.014**	**0.02**	**0.01**	**0**	**0.02**	**0.003**	**0.22**
41) HA-16-3	**16**	**0.3**	**0.008**	**0.017**	**0.02**	**0.02**	**0**	**0.02**	**0.003**	**0.2**
42) US-16-2	**16**	**0.32**	**0.019**	**0.015**	**0.1**	**0.15**	**0.02**	**0.05**	**0.004**	**0.29**
43) YA-18-1	**18**	**0.231**	**0.008**	**0.004**	**0.06**	**0.06**	**0**	**0.04**	**0.0046**	**0.269**
44) JA-18-3	**18**	**0.0281**	**0.02**	**0.02**	**0.1**	**0.01**	**0.06**	**0.05**	**0.0123**	**0.305**
45) SA-18-2	**18**	**0.0277**	**0.016**	**0.008**	**0.03**	**0.02**	**0**	**0.02**	**0.0063**	**0.235**
46) SA-18-1	**18**	**0.288**	**0.015**	**0.007**	**0.03**	**0.02**	**0**	**0.02**	**0.0049**	**0.25**
47) WA-18-1	**18**	**0.304**	**0.018**	**0.027**	**0.13**	**0.08**	**0**	**0.05**	**0.006**	**0.39**
48) JA-20-2	**20**	**0.239**	**0.021**	**0.021**	**0.13**	**0.08**	**0.01**	**0.06**	**0.008**	**0.269**
49) RA-20-2	**20**	**0.351**	**0.011**	**0.016**	**0.13**	**0.05**	**0**	**0.05**	**0.0047**	**0.251**
50) YA-20-1	**20**	**0.208**	**0.009**	**0.008**	**0.06**	**0.07**	**0**	**0.04**	**0.0048**	**0.273**
51) IT-20-3	**20**	**0.76**	**0.011**	**0.014**	**0.11**	**0.02**	**0.01**	**0.04**	**0.0042**	**0.198**
52) SA-20-1	**20**	**0.293**	**0.017**	**0.011**	**0.04**	**0.02**	**0**	**0.03**	**0.0049**	**0.361**
53) BA-20-2	**20**	**0.293**	**0.013**	**0.006**	**0.03**	**0.02**	**0**	**0.21**	**0.0045**	**0.344**
54) JA-20-1	**20**	**0.24**	**0.02**	**0.015**	**0.11**	**0.09**	**0.02**	**0.05**	**0.003**	**0.22**
55) HA-20-1	**20**	**0.29**	**0.009**	**0.004**	**0.02**	**0.01**	**0.01**	**0.02**	**0.001**	**0.33**
56) HA-20-2	**20**	**0.29**	**0.011**	**0.004**	**0.01**	**0**	**0.01**	**0.01**	**0.001**	**0.34**
57) HA-20-3	**20**	**0.28**	**0.009**	**0.005**	**0.03**	**0.01**	**0.01**	**0.02**	**0.001**	**0.33**
58) IT-20-3	**20**	**0.269**	**0.007**	**0.009**	**0.1**	**0.02**	**0.01**	**0.04**	**0**	**0.179**
59) IT-25-3	**25**	**0.287**	**0.009**	**0.011**	**0.07**	**0.04**	**0.01**	**0.03**	**0.0043**	**0.253**

60) YA-25-1	25	0.22	0.008	0.006	0.06	0.05	0	0.05	0.0044	0.259
61) JA-25-3	25	0.259	0.02	0.016	0.06	0.07	0.01	0.05	0.0074	0.257
62) SA-25-1	25	0.28	0.015	0.011	0.05	0.02	0	0.27	0.0054	0.501
63) HA-25-1	25	0.28	0.007	0.005	0.02	0.01	0.01	0.02	0.001	0.41
64) HA-25-2	25	0.28	0.01	0.004	0.04	0.01	0.01	0.03	0.002	0.43
65) HA-25-3	25	0.3	0.011	0.005	0.03	0.01	0.01	0.02	0.001	0.41
66) IT-25-1	25	0.24	0.006	0.008	0.06	0.04	0.01	0.02	0	0.187
67) JA-25-1	25	0.245	0.017	0.013	0.06	0.07	0.02	0.04	0	0.203
68) JA-25-2	25	0.26	0.017	0.012	0.06	0.07	0.01	0.04	0.002	0.2
69) JA-32-1	32	0.239	0.019	0.031	0.11	0.07	0.01	0.05	0.0088	0.269
70) SA-32-2	32	0.297	0.014	0.01	0.05	0.02	0	0.03	0.0047	0.487
71) JA-32-2	32	0.232	0.016	0.034	0.1	0.07	0.02	0.04	0.003	0.209

Table 5.2.3a – Chemical Analysis test results

5.2.4- Chemical test Discussion

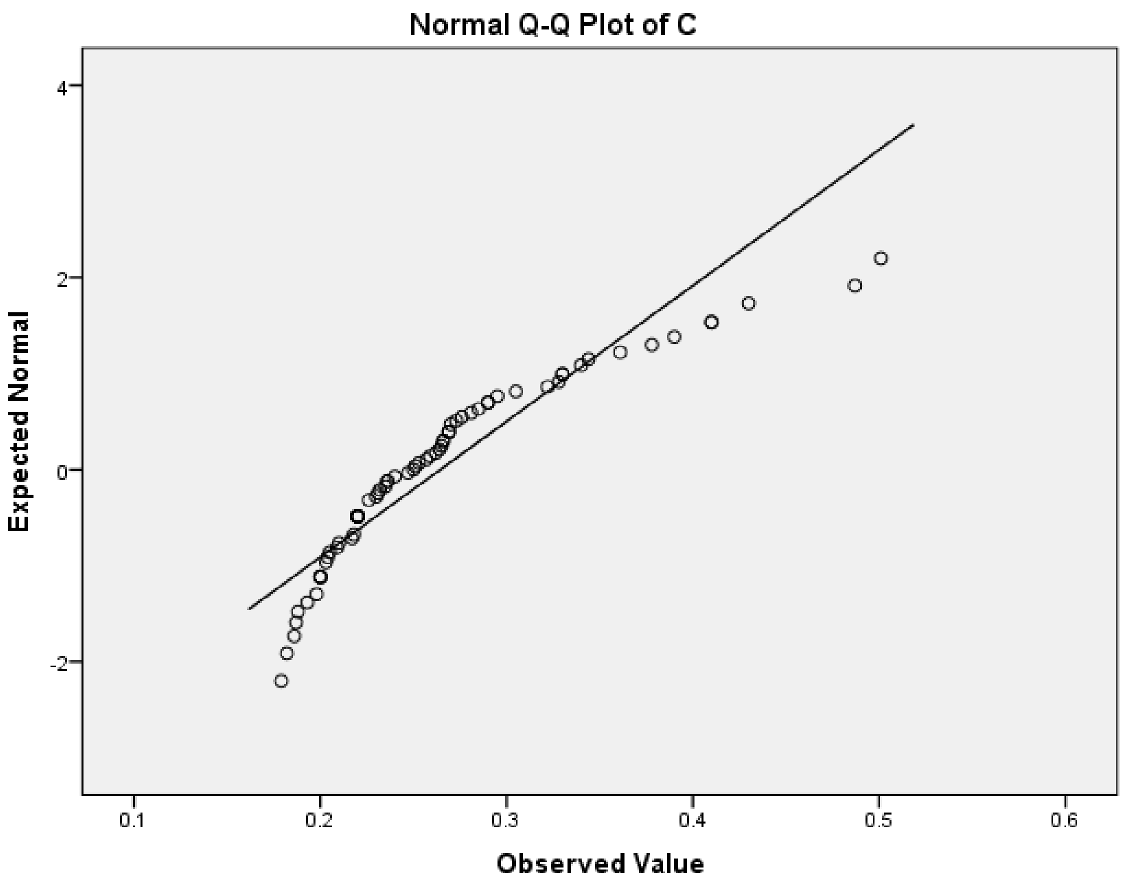

Figure 5.2.4-a: Distribution Graph of Carbon Content vs Normal Line

The carbon content is not normally distributed normally which indicate the input of raw material used before the manufacturing process.

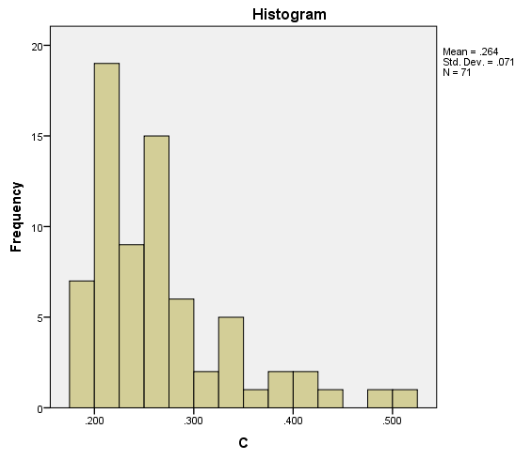

Figure 5.2.4-b: Histogram Carbon Content

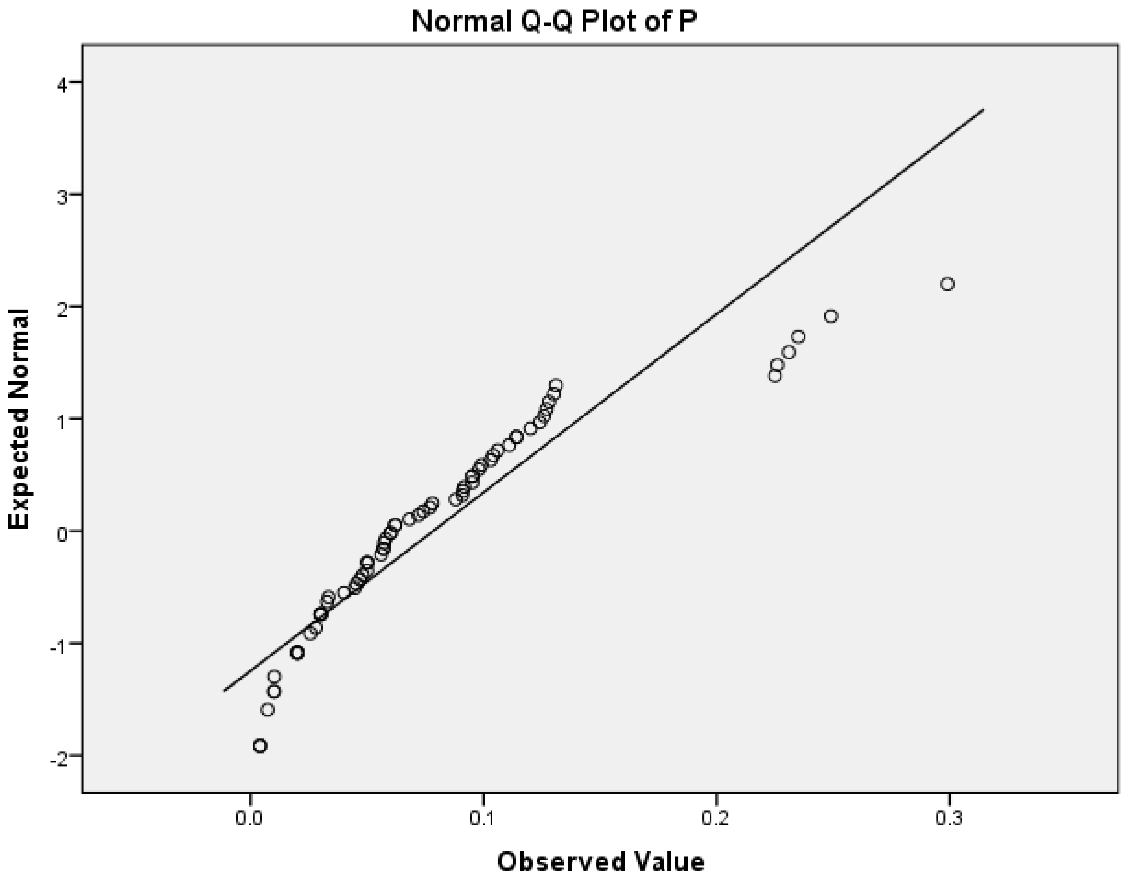

Figure 5.2.4-c: Distribution Graph of Phosphorus Content vs Normal Line

Phosphorous content is not distributed normally which means raw material input quality or quantity.

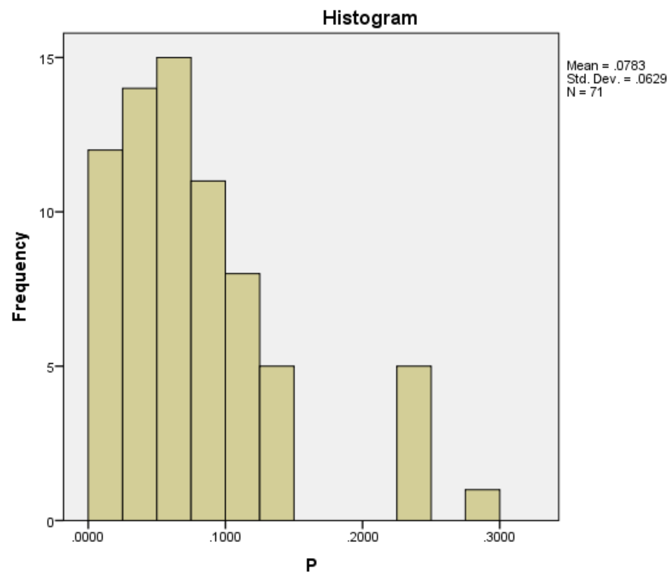

Figure 5.2.4-d: Histogram Phosphorus Content

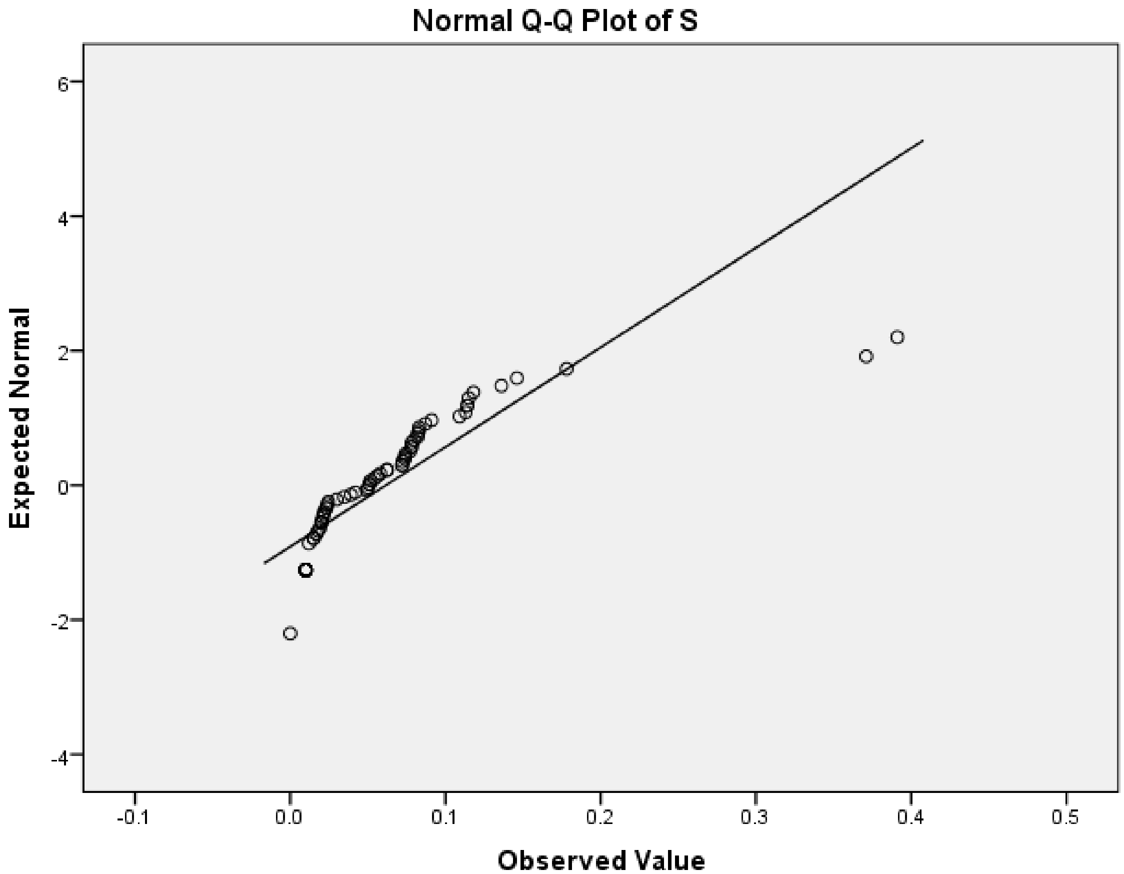

Figure 5.2.4-e: Distribution Graph of Sulphur Content vs Normal Line

Sulphur content is not normally distributed among samples, which means raw material input quality and quantity before manufacturing.

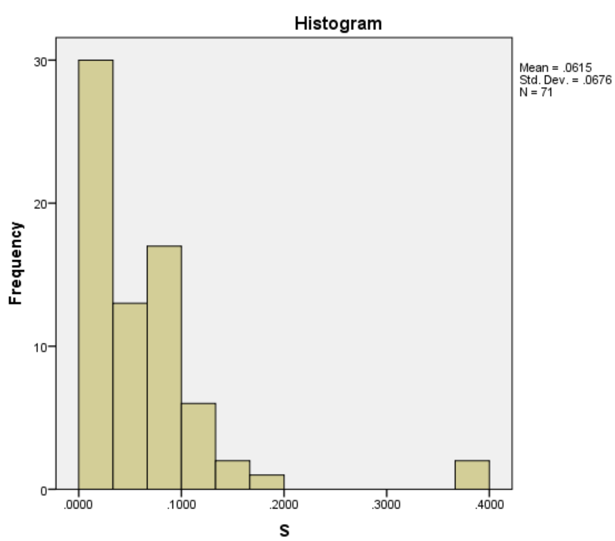

Figure 5.2.4-f: Histogram S Content

Chapter 6

Conclusion and Further Work

6.1 Conclusion

The mechanical properties of steel are directly related to two factors, the chemical composition and the processing method used for the production of steel. If the raw materials used in the steel making process are well balanced, failure of mechanical testing can only be attributed to a subpar rolling process being employed during production.

Analysis of our sample set revealed few samples failed the tensile and chemical tests put by ASTM A615, but a statistical analysis found the standard deviation was high, the normality test showed us that the Carbon, Sulfur and Phosphorus chemical compositions are randomly separated between the 71 samples.

This shows us that the steel that is being produced in Saudi Arabia is meeting the standard, but it will have random mechanical properties. The percentage of elongation for the steel samples was near perfect, the data was fine for the normality test, and had a very small standard deviation.

6.2 Recommendation for Further Work

In the course of this project, the working groups identified various areas where further research was needed, or a more comprehensive review of the documents developed for this project. The areas of further research include the following:

6.2.1- Randomized selection of specimen samples –

A primary difficulty faced by the team during sample collection was the lack of clearance and authorization required for off-the-production-line sample collection. The team was instead provided with specimen samples by the factory staff. This undermines the random sample collection required for a more practical on the field type of result. By working closely with the Ministry of Industries, The Saudi Industrial Property Authority, and SASO – required clearances can be obtained beforehand for a select number of companies to provide true random sample collection, which will give a better picture of the quality of steel rebar production trend prevailing in the country.

6.2.2- Unified Testing Location –

The tensile test and chemical analysis test was carried out at three different locations – namely; SABIC - Jubail, Al Ittefaq Steel – Dammam and Al Hoty – Dammam. In order to achieve a uniform testing environment, we highly recommend carrying out all future tests in this research at one facility. This will minimize any minor errors caused by difference in machinery, testing conditions and handling errors caused by the operator.

6.2.3- Larger Sample Set –

For this project – a total of one hundred and seventy two samples (172) were collected from 4 regions, namely – Dammam, Jubail, Riyadh and Jeddah; off which one hundred and fifty six

(156) samples were tested and analyzed. This is a pioneer research in the field and the scope of expanding on this is vast. Further samples can be collected from various manufacturers in Yanbu, Jeddah & Riyadh to establish this research of significant national value.

6.2.4- National & GCC Level Analysis –

The statistical analysis in this project can be further expanded to a national level including all manufacturers and suppliers to give a true picture of the quality of steel rebars being manufactured in Saudi Arabia.

Once this goal is achieved – an analysis can be done comparing the steel producing countries from the GCC – namely, UAE, Qatar, Saudi Arabia, Kuwait and Oman; to give a broader picture of the quality of steel being produced in the gulf.

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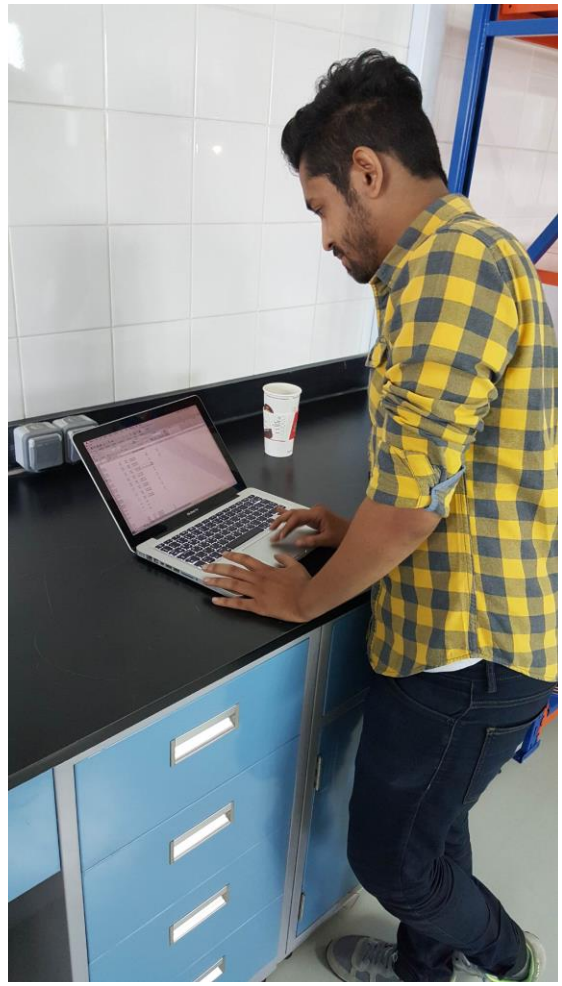
Appendix

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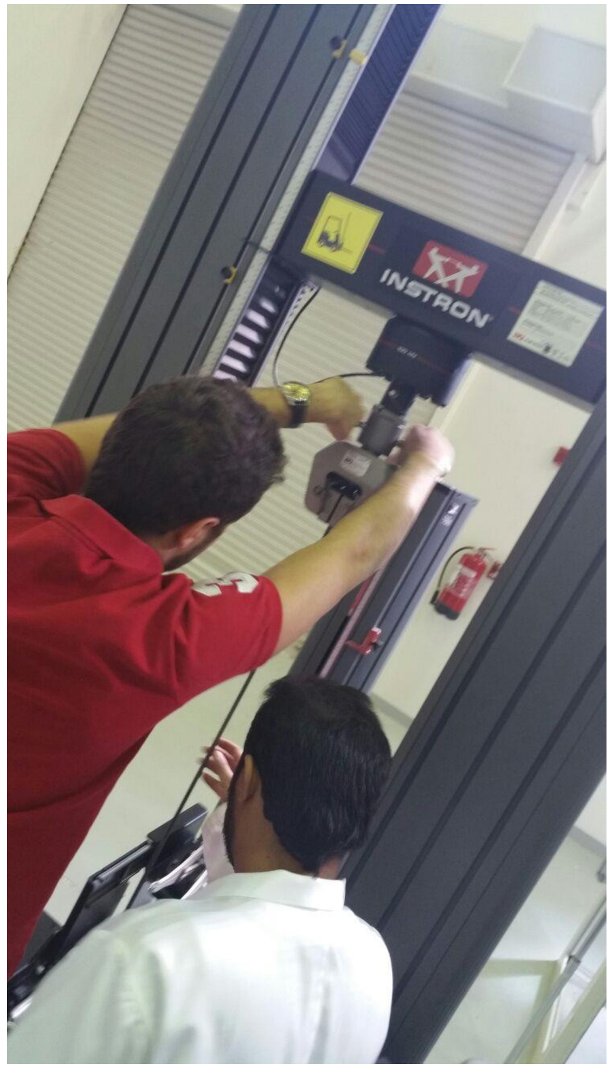
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