Sudan University of Science and Technology

College of Post-Graduation studies

School of Mechanical Engineering

ANALYTICAL STUDY AND EVALUATION OF QUALITY IN GIAD IRON INDUSTRIES

دراسة تحليلة لتقويم الجودة في مصانع جياد للمنتجات الحديدية

Thesis submitted in partial fulfillment for the Requirements of Master of Science in Mechanical Engineering (Production)

by:

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بسم الله الرحمن الرحيم

وقل رب زدني علما

صدق الله العظيم

Dedications

This work is dedicated to my family and many friends. A special feeling of gratitude to my loving parents, whose words of encouragement and push for tenacity ring in our ears. Our brothers and sisters.
Also, this work dedicated to many friends, they have supported me throughout the process. I will always appreciate all they have done.
In addition, I dedicate this work to Giad Iron Industry family, special dedications are owned to the Reinforced Steel Bar Unit.

Last, not least dedicate for our homeland Sudan.

Acknowledgements:

There are people like candles burn to light the way of the others, during this research I found many, give deep helping, the thanks are not giving them their rights.

I would like to thanks my master, Dr. Yassin Hamedan for his supporting to complete this research.

My parents whom words of encouragement, my brothers and sisters, my friends, Tanks any one helps in any field and all the teachers passed through our education levels.

Finally, I wish to thank all project readers who offered countless interesting, valuable, and stimulating suggestions.

In closing we are deeply grateful our parents for their endless love and patience.

Abstract

Through the last years the reliable and qualified products is highly desirable. In this study the Giad steel bar evaluated in purpose to determine its quality and process capability using the statistical method and ASTM 615, the study conclude that the out of control points increased with time which indicate the machine tools deterioration, which is approved by process capability analysis, when its show process not capable to produce within control limit according to ASTM 615, which is equal 0.3806. The most out of control points is above the specification limit which is mean the higher strength and that does not affect usability but still consider out of control in quality aspect.

III. الخلاصة

مؤخرا المنتجات الاكثر جودة وإعتمادية هي الاكثر طلبا في الاسواق. من خلال هذه الدراسة تم التطرق الي منتجات جياد من السيخ بغرض دراسة مستوي الجودة فيها والمقدرة علي الانتاج بمستويات الجودة المطلوبة وذلك لمعرفة مناطق الخلل ومعالجتها لرفع الجودة في مصنع جياد. وفي هذه الدراسة تم استخدام الطريقة الاحصائية وِ ASTM 615 واستخدام مخططات الجودة واستخدام مخططات تحليل الاداء تم التوصل الي ان النقاط الغير مطابقة للجودة تقع في الجانب العلوي لمخططات الجودة وفي تزايد مع مرور الوقت وذلك ان دل انما يدل علي زيادة في اهلاك ماكينات الانتاج والذي اثبت من خلال عمل دراسة المقدرة علي الانتاج والتي بدورها اثبتت ان عملية التصنيع غير قادرة علي الانتاج في حدود الجودة حسب ASTM 615 والتي تساوي 0.3806 . اغلب النقاط التي كانت غير مطابقة للجودة من الحد الاعلي والذي يدل علي ان المنتج أعلى شدة وهذا لايؤثر علي الاستخدام ولكن ايضا تعتبر غير مطابقة للجودة.

Table of Contents:

The List of Figure:

List of Tables:26

List of Abbreviations:

No	Abbreviation	Meaning
1	ASTM	American Society for Testing Materials
2	UCL	Upper Control Limit
3	LCL	Lower Control Limit
4	USL	Upper Specifications Limit
5	LSL	Lower Specifications Limit
6	NC	Non-Conformities
7	XRD	X- Ray Diffraction
8	T.St	Tensile Strength
9	Y.St	Yield Strength

CHAPTER ONE: INTRODUCTION

1. Introduction

1.1. Preface:

Free economic policies have led to the opening up of global markets and their integration into a single global market in which companies productive and service institutions compete to win the confidence of customers to raise their balance.

These companies and institutions have followed various ways and means to produce their products in a way that meets the needs of the consumer and through these methods follow the quality systems and the adoption of standards.

1.2. The problem statement:

Giad iron industries is one of Sudanese industries that produce the reinforced steel which is subjected to highly competitive environment, to stay competitive with good reputation, continues quality evaluation and improvement required.

1.3. The Scope of the study:

The study conducted at Giad Iron Industry which is located in the state of Gezira, Kamelin Locality, 50 km south of Khartoum. The total area is 25000 m 2. the current, and future facilities cover the area of 30500 m^2.

1.4. The aim of the study:

The study aim is to evaluate the quality of Giad iron Industry steel bar.

1.5. The objectives of the study:

- Evaluate the quality control processes used in the Giad factories and determine their effectiveness in giving the required quality.
- Use the statistical control tools to evaluate Giad Iron factory products.

1.6. Methodology:

1.6.1. Method:

Measuring and evaluating the quality level of the iron factory products of the Giad industrial complex and comparing them with the international standards for measuring

ASTM 615 and the standard specifications of the Sudanese Organization for Standardization and Metrology.

1.6.2. Materials:

- ASTM 615 Standards.
- Specifications of the Sudanese Organization for Standardization and Metrology.
- Giad iron industry data for steel product.
- Microsoft Excel

CHAPTER TWO: LITERATURE REVIEW

2. Literature Review

Test used for Steel bar

There are several tests used in Giad Iron industry to show the validity of the steel bar that produced by the industry, and they are.

2.1. Tensile Test

The tensile test is the most common procedure for studying the stress–strain relationship, particularly for metals. In the test, a force is applied that pulls the material, tending to elongate it and reduce its diameter, as shown in Figure 2.1(a). Standards by ASTM (American Society for Testing and Materials) specify the preparation of the test specimen and the conduct of the test itself. The typical specimen and general setup of the tensile test is illustrated in Figure 2.1(b) and (c), respectively. The starting test specimen has an original length L_o and area A_o. The length is measured as the distance between the gage marks, and the area is measured as the (usually round) cross section of the specimen. During the testing of a metal, the specimen stretches, then necks, and finally fractures, as shown in Figure 3.2.

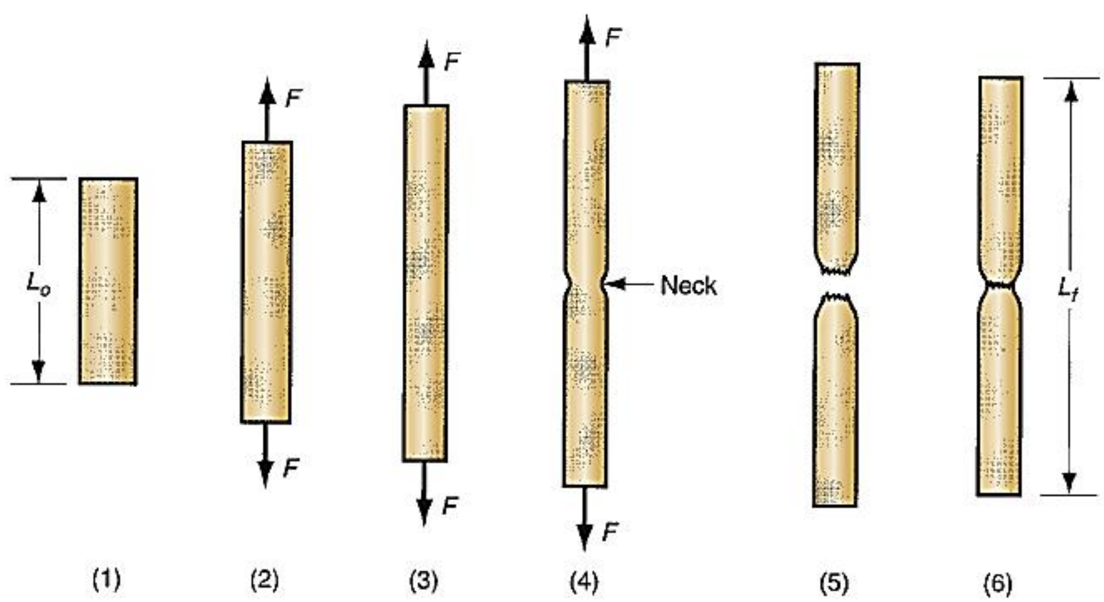

Fig 2.1 Typical progress of a tensile test: (1) beginning of test, no load; (2) uniform elongation and reduction of cross-sectional area; (3) continued elongation, maximum load

reached; (4) necking begins, load begins to decrease; and (5) fracture. If pieces are put back together as in (6), final length can be measured.

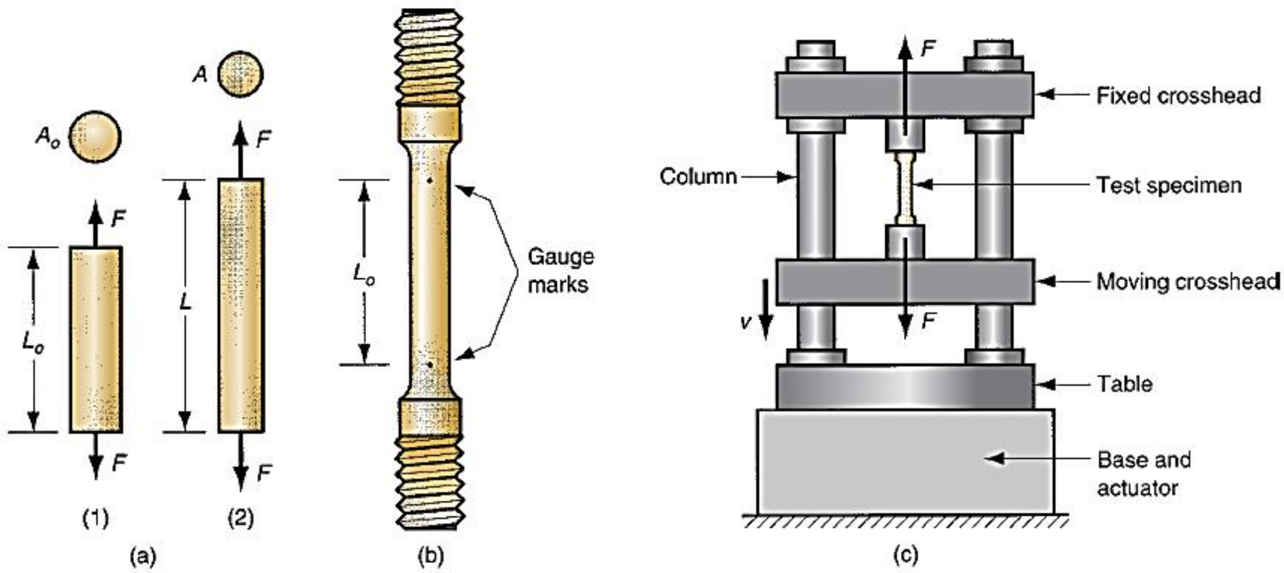

Fig 2.2 Tensile test: (a) tensile force applied in (1) and (2) resulting elongation of material; (b) typical test specimen; and (c) setup of the tensile test.

The load and the change in length of the specimen are recorded as testing proceeds, to provide the data required to determine the stress–strain relationship. There are two different types of stress–strain curves: (1) engineering stress–strain and (2) true stress–strain. The first is more important in design, and the second is more important in manufacturing.

The engineering stress and strain in a tensile test are defined relative to the original area and length of the test specimen. These values are of interest in design because the designer expects that the strains experienced by any component of the product will not significantly change its shape. The components are designed to withstand the anticipated stresses encountered in service. A typical engineering stress–strain curve from a tensile test of a metallic specimen is illustrated in Figure 2.3. The engineering stress at any point on the curve is defined as the force divided by the original area. [1]

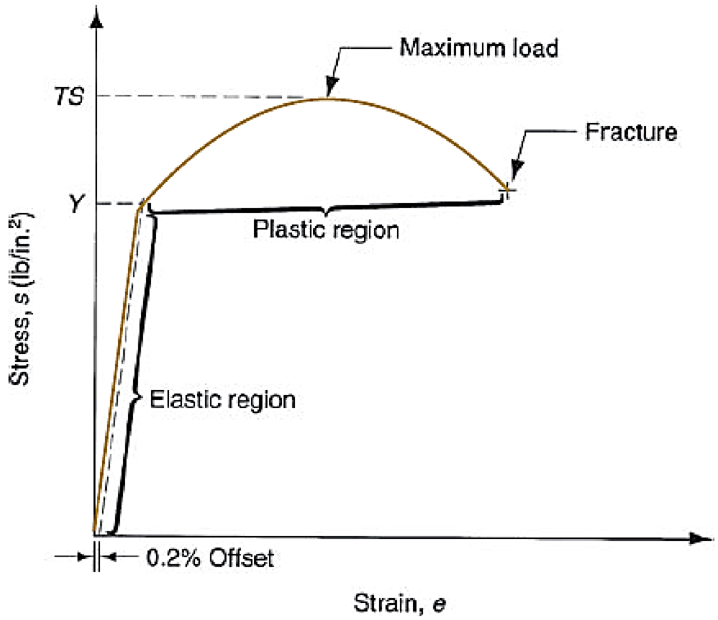

Fig 2.3 Typical engineering stress–strain plot in a tensile test of a metal.

True Stress–Strain Thoughtful readers may be troubled by the use of the original area of the test specimen to calculate engineering stress, rather than the actual (instantaneous) area that becomes increasingly smaller as the test proceeds. If the actual area were used, the calculated stress value would be higher. The stress value obtained by dividing the instantaneous value of area into the applied load is defined as the true stress [1].

2.2. ASTM 615

This specification covers deformed and plain carbon steel bars in cut lengths and coils for concrete reinforcement. Steel bars containing alloy additions, such as with the Association for Iron and Steel Technology and the Society of Automotive Engineers series of alloy steels, are permitted if the resulting product meets all the other requirements of this specification. [2]

2.3. Previous Studies

The study done at Sudan they study the quality of reinforcing steel bars. Reinforcing bar samples were assembled from seven different Iron and Steel factories in Khartoum – Sudan. Different samples were weighted and their effective diameters were measured. 12 mm and 16 mm diameter samples from the seven factories were tested for tensile strength and elongation was measured. Test results were compared to the British, American, and Sudanese standards. Tests showed that all factories have met the standard yield strength, while some factories failed to meet the ultimate strength, elongation, effective diameter and weight standards. [3]

Ignatius Study the metallurgy of ASTM A615/A615M Gr. 60 steels made from three different chemistries to suggest an economically advantageous route to produce a steel grade that saves the extra cost of alloying elements. Metallographic examinations, along with microhardness and XRD studies, were performed to rate the steel chemistries based on their superheats. This study of the steel grades revealed that producing steel for requisite standards like ASTM615/A615M Grade 60 may not be dependent on starting superheat but on the chemistry and rolling process. Study of the three chemistries A, B and C indicated that the standards were met in all 3 chemistries; however, sample A had the lowest cost chemistry and therefore is a suggested route for this product. [4]

The study conducted by Sanmbo Balogun in Nigeria have shown that bars produced through conventional rolling requires appropriate modification of its chemical composition in order to obtain the desired mechanical properties such as strength. However, the high cost factor involved in composition adjustment makes such approach unattractive. Rather, the application of the combination of systems of controlled rolling and controlled cooling proves to be the best option. This system however, requires some variations in processing parameters to suit individual plant production peculiarities. In this paper attempt is made to study the production challenges and opportunities the steel millers are facing in Nigeria. Previous works in this area are also reviewed with a view to charting the way forward. Experimental studies and process monitoring were carried out at some designated rolling mills in Nigeria. [5]

2.4. Giad Iron Industry:

The factory is located in the state of Gezira, Kamelin Locality, 50 km south of Khartoum. The total area is 25000 m 2. the current, and future facilities cover the area of 30500 m^2.

2.4.1. The main products of the industry:

Reinforcement steel bar of different sizes with a capacity of 180,000 tons per year, and Iron ingots with a capacity of 9000 tons per year

2.4.2. Raw materials used

The main material used is iron scrap with smelting aids such as lime, oxygen and other additives to modify iron withdrawal and improve the mechanical properties.

2.4.3. Extraction rate*:*

The extraction percentage is the percentage of the standard product attributable to the raw material used.

Raw material used: The raw material that was entered is rolling to get the best extraction ratio, you need to increase the standard product and reduce losses.

The extraction percentage is of the utmost importance as it has a clear impact on the profitability of the organization. The more the percentage of extraction increases, the higher the quantity of the standard product, and thus less losses. This increase has different and multiple effects starting from the user through the heating process and different production processes until reaching the final product which we will study with you. In a scientific and logical way to reach the appropriate solutions that lead to improving the percentage of extraction.

2.4.4. Inspecting and receiving scrap*:*

The steps:

1. When the scrap arrives from outside the company, the representative of the Procurement Department of the Scrap Screening Committee assures that the scrap comes from a party that has a valid supply contract with GIAD Iron Industries, or a supply order.
2. In the case of scrap received from inside the company's factories, step (1) is not applied.
3. When the scrap coming from outside the company reaches the point of scale, the scale operator will weigh the vehicle and notify the inspection committee to do the following:
   - Ensure that the scrap is dry and free from dust
   - Ensure that the scrap is free from insulation materials, such as: plastic, wood, construction material residue.
   - Ensure that scrap is free from non-ferrous metals, such as: copper, lead and aluminum.
   - Ensure that the scrap is free from explosive materials.

- Ensure that the scrap is free from closed containers, such as: gas pipelines, tanks.

4. In the event that the scrap matches the specifications according to the decision of the examination committee, the scrap store keeper receives the quantity according to the procedure for controlling the warehouses and warehouses - P-WH - and filling in the form of a document receipt -WH / 01- after re-weighing the truck when it is empty, with an explanation of the grade of scrap. According to the following classification:
   - Heavy ready scrap: It is an iron made of heavy type, free from cast iron, not exceeding (50 * 50 * 70) cc.
   - Heavy, unprepared scrap: It is an iron made of heavy type, free from cast iron, but it needs cutting and preparation.
   - Compressed light scrap: It is light scrap, free from impurities, insulators, construction waste, and the like, compressed into blocks of sizes not exceeding (60 * 60 * 70) cc.
   - Light, non-compressed scrap: It is light scrap free from impurities, insulators, construction waste and the like, which needs to be prepared and pressed.
5. In case of non-conformity according to the decision of the examination committee, the representative of the Quality Control Department will issue a card NC / 01 refused to reserve the quantity and make a NC / 01 nonconformity report, and confirm that this is documented in the inspection form.
6. In the case of partial conformity, identical and non-conforming quantities are determined according to the decision of the examination committee to continue supervising the unloading of the matching quantities and recharging the non-conforming quantities, then completing the following work:
   - Corresponding quantities: The scrap store takes delivery according to the procedure mentioned in item.(4)
   - Non-conforming quantities: The Quality Control representative reserves the non-conforming scrap and completes the procedures mentioned in the filing.

2.4.5. Inspection*:*

Purpose: To make the necessary checks to monitor the quality of production inputs, the materials received for the factory and the final product and to verify their requirements for the approved specifications and standards, Figure.(10-3)

Field of application: This method covers production inputs, materials received for the factory and the final product.

2.4.6. Responsibilities:

The Quality Assurance Manager, in coordination with the Head of the Quality Control Department, is responsible for ensuring that the certificates of analysis for production inputs and materials received for the factory comply with the approved specifications.

The Head of the Quality Control Department is responsible for:

- Direct supervision of quality laboratory technicians, distribution of work and follow-up of its implementation
- Approving laboratory reports and submitting them to the Director of Quality Assurance after commenting on them.

The production technicians and workers responsible for feeding the oven fill the suspicious raw materials and inform the head of the quality control department in coordination with their superiors.

The lab technician is responsible for preparing and weighing samples, then conducting checks and recording data in a computer.

The sampling and examiner is responsible for:

- Check the raw materials when a miss roll occurs and report abnormal defects in production inputs.
- Sampling and delivery to the laboratory

2.4.7. Quality Assurance of Steel bar:

Examination of production inputs and materials received for the factory:

The Director of Quality Assurance makes sure that there is an analysis certificate from the origin with each shipment of production inputs and then in cooperation with the head of the Quality Control Department, it matches the physical specifications and chemical content mentioned in the analysis certificate with the approved specifications, and checks in kind (VISUAL TEST) to verify the type The materials are outwardly apparent, then the results are recorded in an internal materials inspection report, and in case the goods are identical, the Quality Assurance Manager signs the receipt document for the warehouses to authorize their use, and in case of non-conformity, he follows the way of controlling the materials and for non-conforming products.

In the case of raw materials (BILLET), a sample is taken for laboratory, for processing according to the working method (WI-IT-01), and then the chemical composition of the METAL ANALYZER spectroscopy will be tested according to the working instruction (WI-IT-02).

2.4.8. Production processes:

2.4.8.1. Melting Section:

The melting process of iron is carried out with electric ovens (electric arc), while the molten is purified from impurities, and the percentages of iron, carbon, and other elements are set, and by continuous plumbing method, iron alloys are obtained according to international specifications and sizes 6000 * (130 * 1230-100 * 100) mm and the furnace capacity is 25 tons Per flower

2.4.8.2. Rolling section:

In the rolling section, the iron ingot is reheated inside the reheating furnace using sulfur-free fuel oil and is pushed to the rolling machines to pass successive rolling operations to obtain the final product as the production capacity of the rolling section reaches 600 tons per day. The market in an automatic way to prick the way for the consumer

Iron in various stages of production undergoes multiple tests with the latest equipment to obtain a new product with international specifications

2.4.9. Auxiliary units:

There is a unit for collecting and purifying the vapors and gases resulting from melting furnaces

A unit of oxygen production at a rate of 50 square meters per hour and you will get nitrogen gas

The power factor improvement unit, which reduces electricity consumption and reduces the impact of b / b resulting from smelting operations on the national grid.

2.4.10. Productive stages:

2.4.10.1. Heating:

The ingot is heated after being prepared for 3m lengths, and you can reheat the oven to a temperature of 1200-1150

2.4.10.2. Rolling mill:

Rolling stage starts after heating the product to a temperature of 1200-1150 ° C where the pellet becomes easy to form and for you using sulfur-free French oil and it is a mineral formation in each stage to reduce the cross section area and increase the length as it passes through three stages

- Primary rolling
- Alloy rolling
- Final rolling
- Heat treatments

This is the stage after product gets the final form of the rolling process, where it is treated with water with a pass in a box with high pressure pipes to relive the stresses.

2.4.10.3. Finishing:

After the rolling operations, the product is finished and pushed to the cooling area to be cut according to the standard lengths, then packed automatically in bundles and then transferred to the consumer.

The steel bars undergo multiple tests according to international specifications and that by using advanced laboratory equipment to obtain a product that conforms to international specifications.

CHAPTER THREE: METHODOLOGY

3. Methodology:

3.1. Tensile Testing Machine.

The tensile testing machine used to perform the test was the universal testing machine with load capacity 1000 KN.

Fig 3.1: Universal Testing Machine used in the study

3.2. ASTM615 Specifications.

This specification covers deformed and plain carbon steel bars in cut lengths and coils for concrete reinforcement. Steel bars containing alloy additions, such as with the Association for Iron and Steel Technology and the Society of Automotive Engineers series of alloy steels, are permitted if the resulting product meets all the other requirements of this specification. [2]

Table 3.1. the Mechanical properties limits according to ASTM615

No	Mechanical Properties	ASTM615 USL	ASTM615 LSL
1	Yield Strength (N/mm2)	650	460
2	Tensile Strength (N/mm2)	750	530
3	Ratio of T.St/Y.St	1.15	
4	Elongation	12	

3.3. Microsoft Excel Program.

The Microsoft excel program, used to calculate and plot the control charts they will be shown in the results chapter, also the capability study used to evaluate the process calculated and plotted using Microsoft excel program.

The version used is Microsoft Excel 2016.

3.4. Giad Iron Industry steel bars.

Table 3.2: The dimensions and weight of different Giad iron industry steel bars.

No	Bar Size (mm)	Number of Bar per 2ton	The Weight per unit length (Kg/m)		
			Upper limit max (+3%)	Standard	Lower limit max (+3%)
1	10	270	0.636	0.617	0.598
2	12	188	0.915	0.888	0.860

3	16	105	1.625	1.578	1.530
4	18	083	2.060	2.000	1.940
5	20	067	2.544	2.470	2.396
6	25	043	3.970	3.854	3.738
7	32	026	6.502	6.313	6.124
The standard length for all bar is 12m					

3.5. Method.

the statistical method used to evaluate the Giad Industry steel bar quality, and also using the ASTM615 specifications.

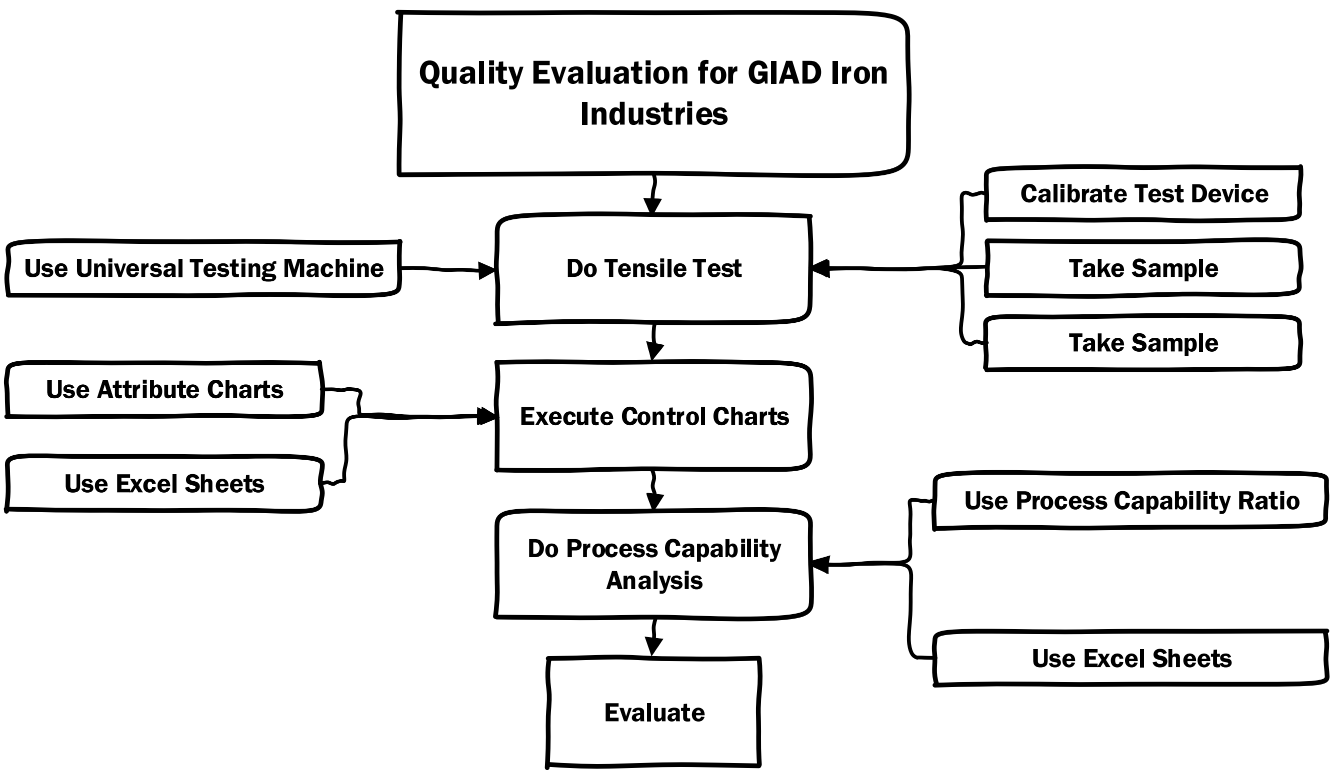

Fig 3.2. The Evaluation Process Flowchart.

3.5.1. Data Collection Method.

The test equipment's were calibrated and this done for each test individually.

The specimen sampled from each patch according to ASTM615 standard and the production data collected for each patch. The specimen prepared according to ASTM615 standard

Then the previous test done for each specimen and the data collected.

The accumulated data saved in the sheets for the successive production 12^{th} weeks.

3.5.2. The Testing Method:

The testing is done according to ASTM615, starting with determining both tensile and bending requirements to prepare the specimen, weighting the specimen, finishing the specimen, number of tests, testing reports, and test inspection. All this could be found in the ASTM615 attached at appendix.

3.5.3. The Data Analysis

The statistical method used to examine the Giad iron industry steel bar quality as well as the whole process capability analysis also done to evaluate its capability.

The collected data analyzed using the Microsoft excel program through calculate and plotting the control charts for each week.

Also, the process capability analysis done using the Microsoft excel program.

CHAPTER FOUR: RESULTS & DISCUSSION

4. Results & Discussion:

4.1. Preface:

In this chapter the quality control chart constructed using ASTM standard for yield strength for the steel bar that produced by Giad Iron Industry for 12th succession week.

4.2. Control Charts for yield strength of Giad Iron industry bar:

The figure below shows the steel bar yield strength control chart at the 1st week, without nonconformities.

Table 4.1: Yield strength data for the first week.

Yield Strength				
Test Result	**LSL**	**Mean**	**USL**	**Week Mean**
587.13	460	555	650	602.26125
593.95	460	555	650	602.26125
605.1	460	555	650	602.26125
639.26	460	555	650	602.26125
592.81	460	555	650	602.26125
574.12	460	555	650	602.26125
631.92	460	555	650	602.26125
593.8	460	555	650	602.26125

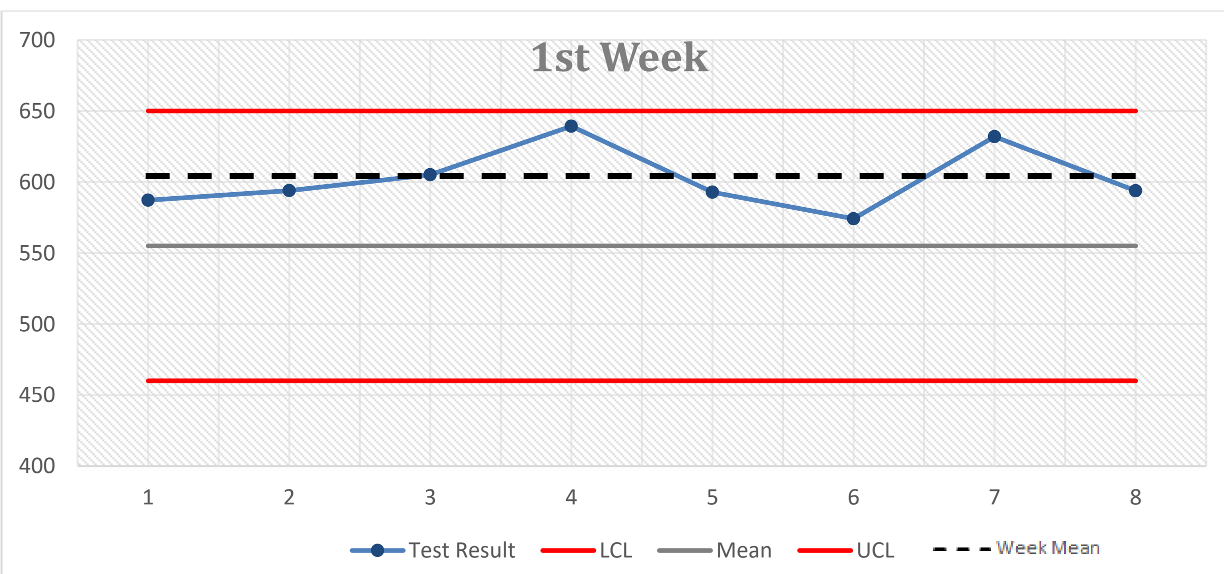

Fig 4.1 The steel bar yield strength control chart for the first week.

The figure below shows the steel bar yield strength control chart at the 2nd week, where sample no 3, and 22 does not conform the specification limits.

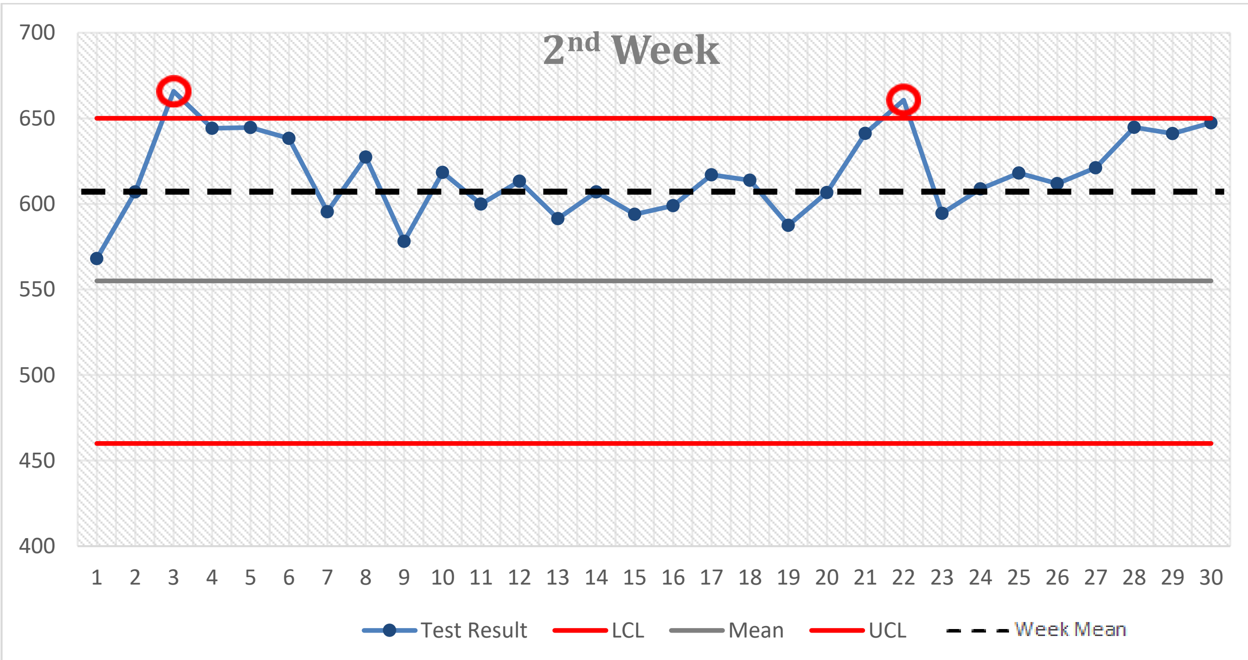

Fig 4.2 The steel bar yield strength control chart for the 2nd week.

The figure below shows the steel bar yield strength control chart at the 3rd week, where only sample no 11 does not conform the specification limits.

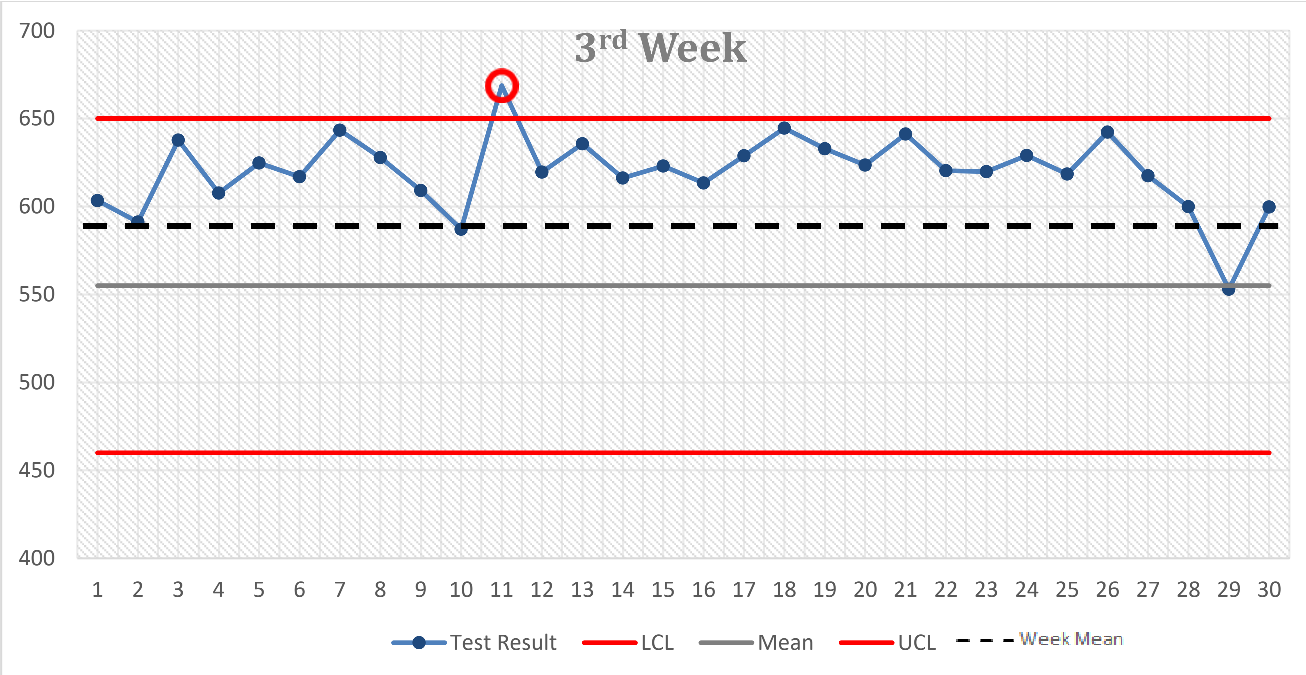

Fig 4.3 The steel bar yield strength control chart for the 3rd week.

The figure below shows the steel bar yield strength control chart at the 4th week, where sample no 8, 9, and 16 does not conform the specification limits.

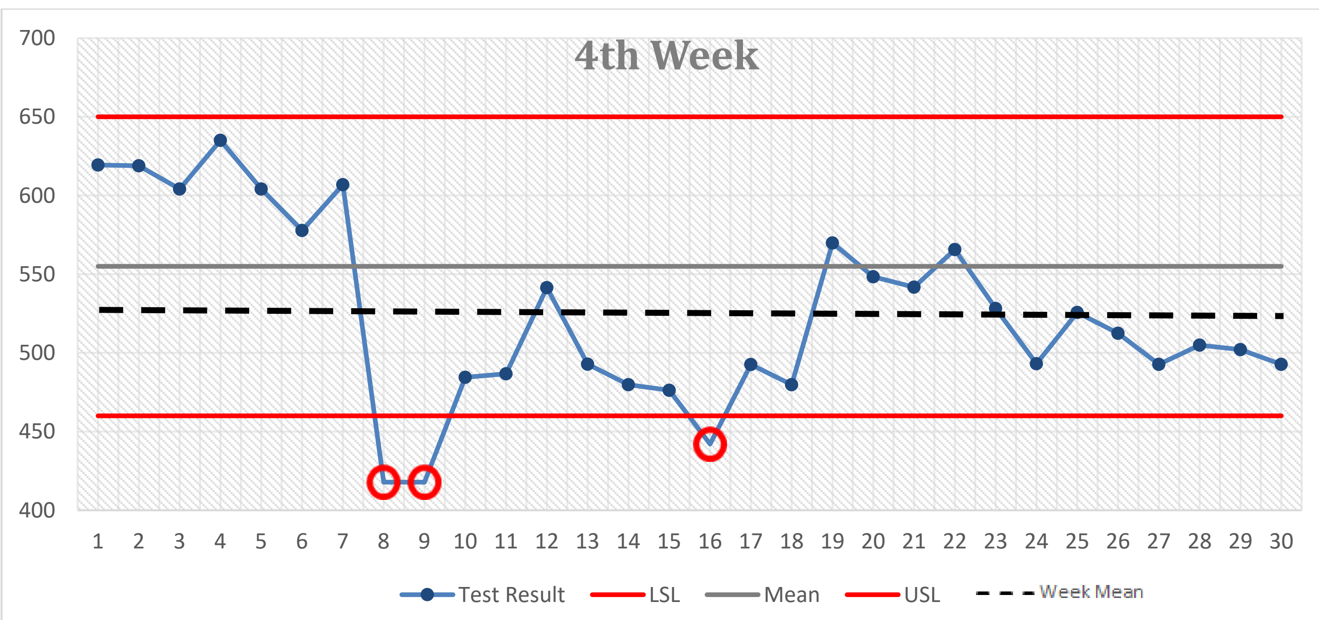

Fig 4.4 The steel bar yield strength control chart for the 4th week.

The figure below shows the steel bar yield strength control chart at the 5th week, where sample no 3, and 22 does not conform the specification limits.

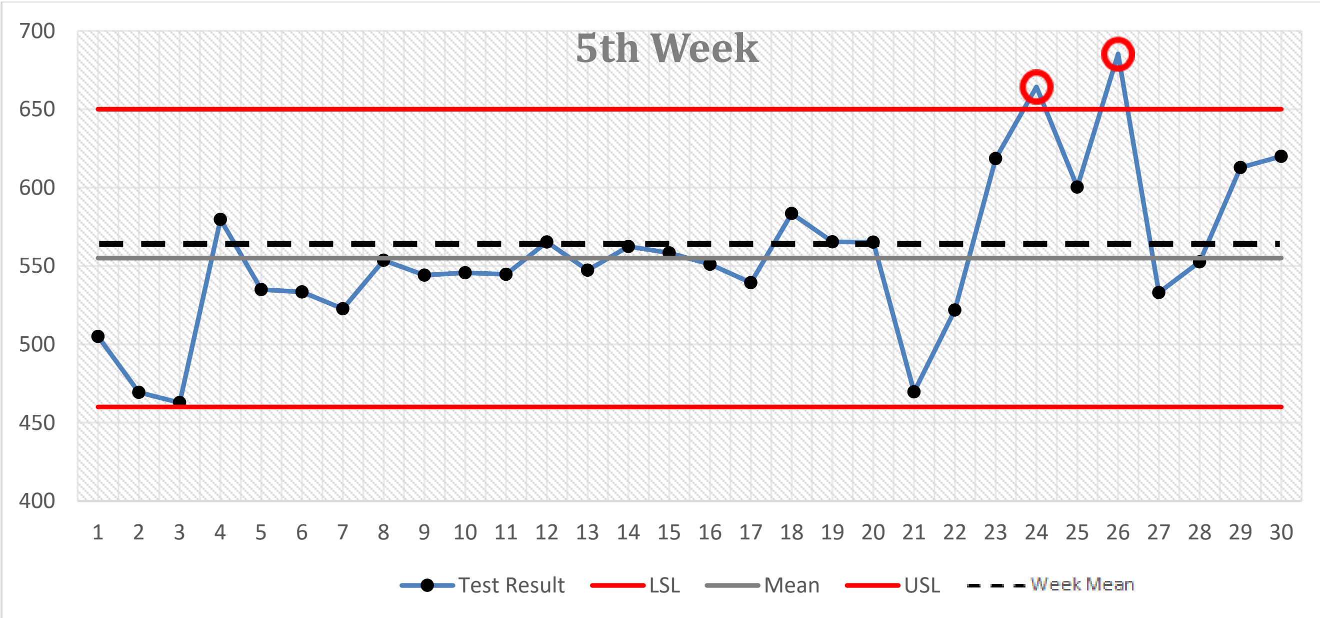

Fig 4.5 The steel bar yield strength control chart for the 5th week.

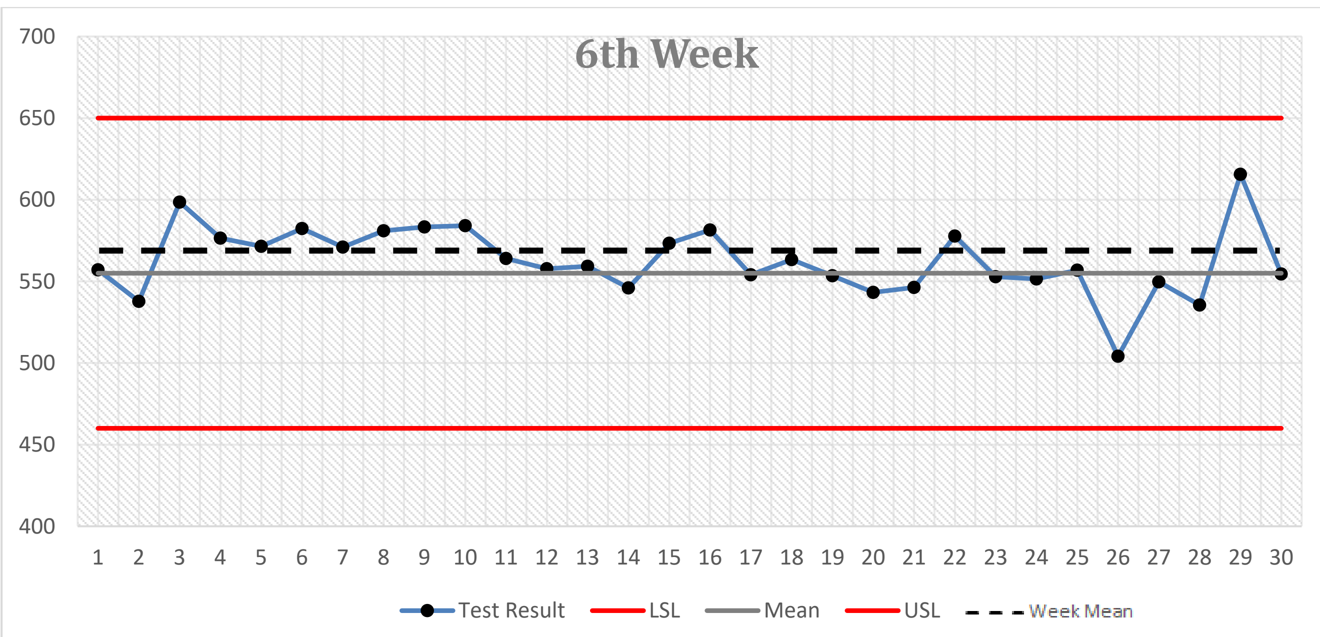

Fig 4.6 The steel bar yield strength control chart for the 6th week.

The figure below shows the steel bar yield strength control chart at the 7th week, where sample no 11, and 12 does not conform the specification limits.

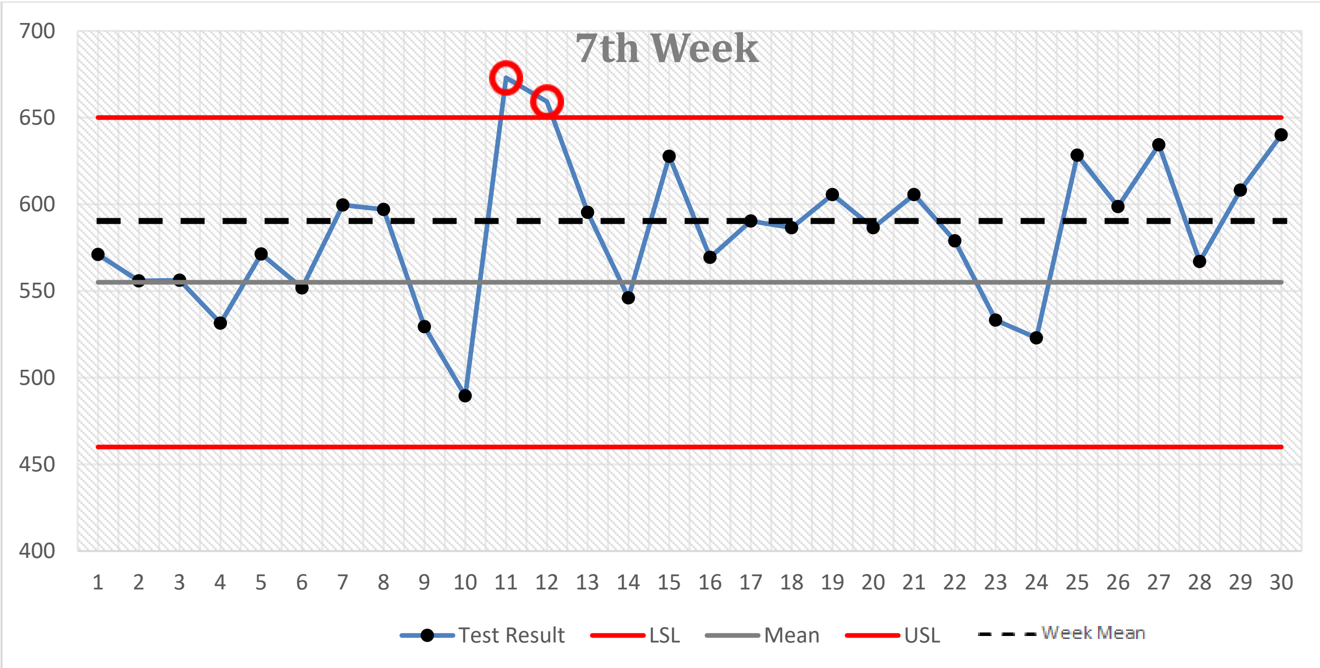

Fig 4.7 The steel bar yield strength control chart for the 7th week.

The figure below shows the steel bar yield strength control chart at the 8th week, where sample no 16, 17, and 26 does not conform the specification limits.

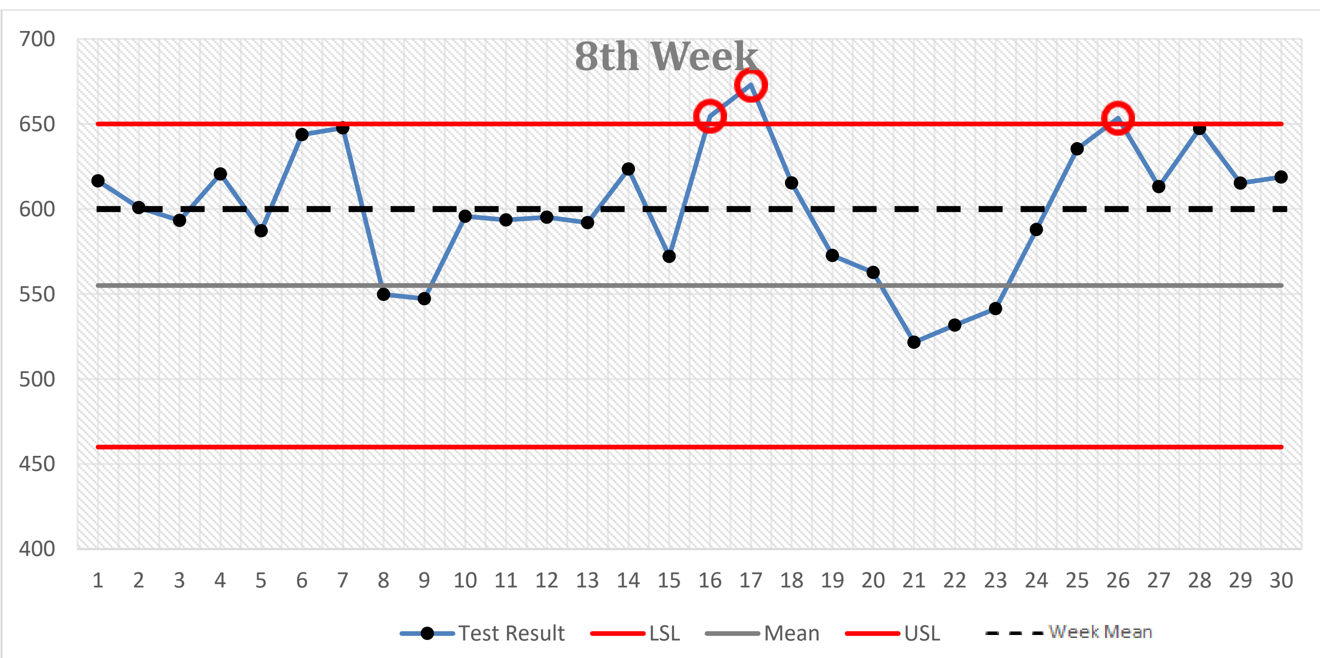

Fig 4.8 The steel bar yield strength control chart for the 8th week.

The figure below shows the steel bar yield strength control chart at the 9th week, where sample no 1, 2, 6, 7, 9, 10, and 11 does not conform the specification limits.

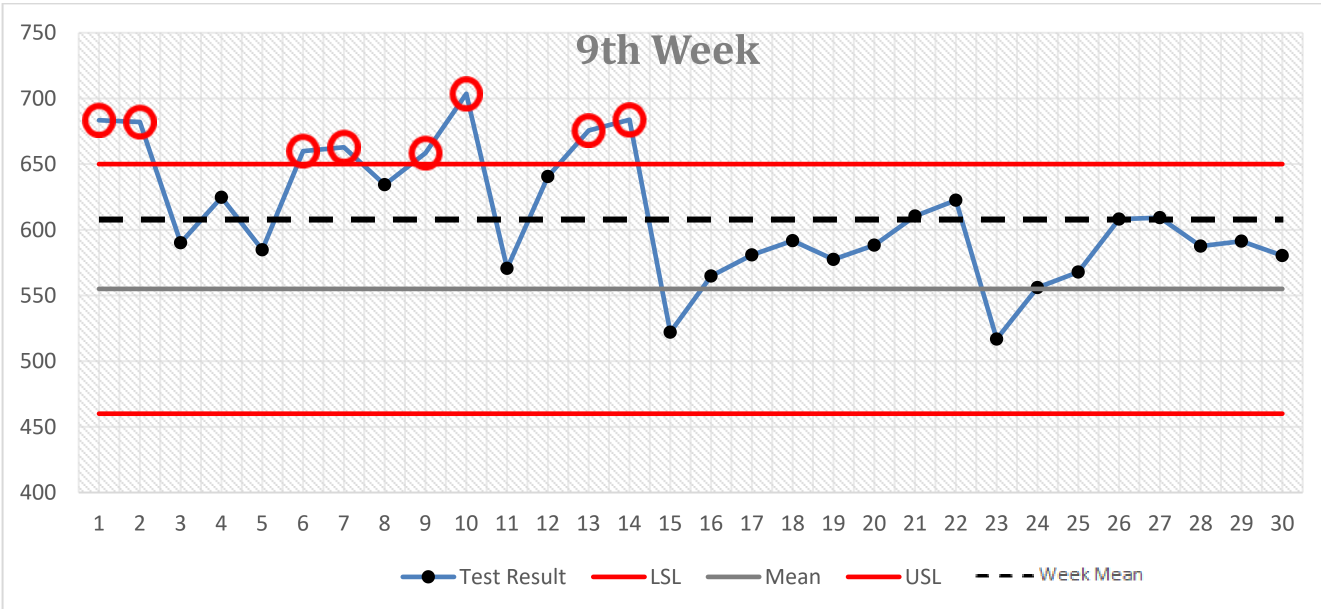

Fig 4.9 The steel bar yield strength control chart for the 9th week.

The figure below shows the steel bar yield strength control chart at the 10th week, where sample no 1, 4, 7, 14, 15,and 17 does not conform the specification limits.

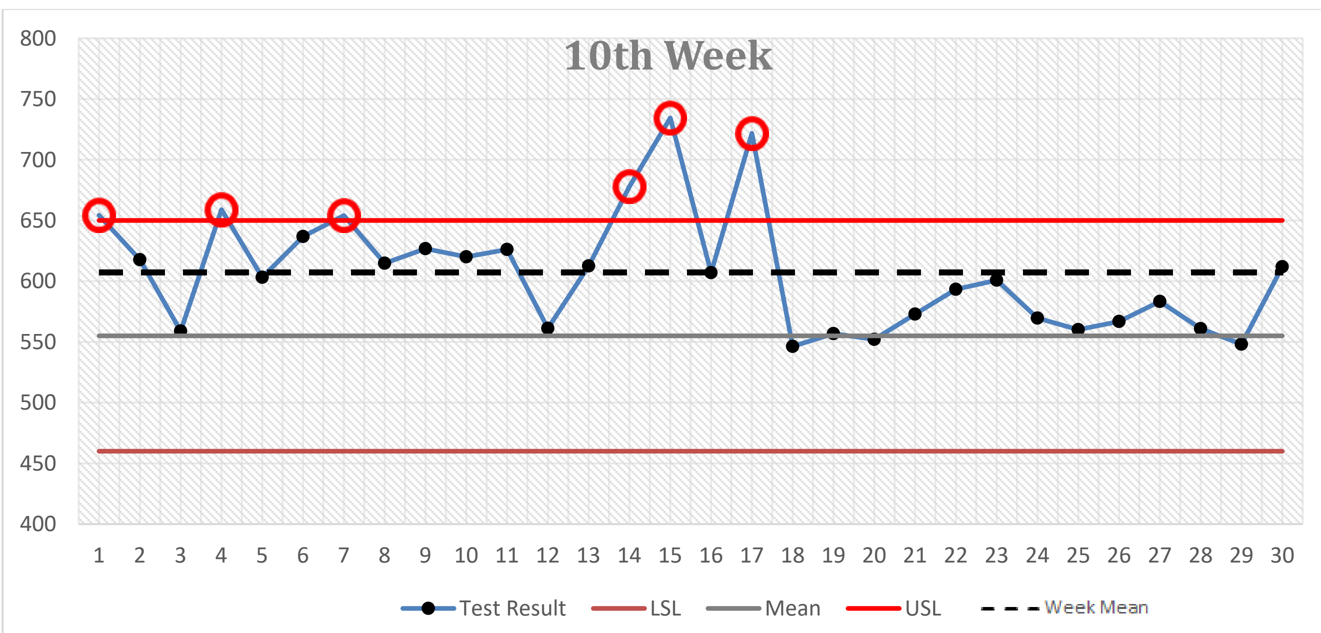

Fig 4.10 The steel bar yield strength control chart for the 10th week.

The figure below shows the steel bar yield strength control chart at the 11th week, where sample no 6, 10, 12, 13, 27, 29 and 30 does not conform the specification limits.

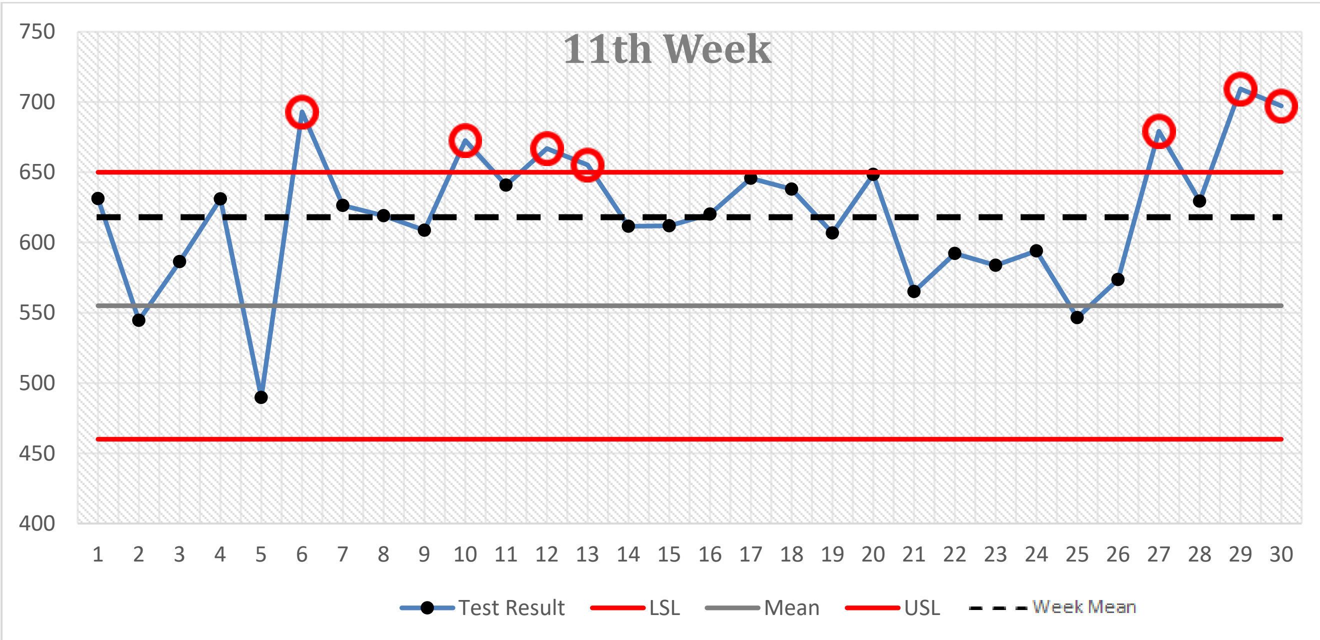

Fig 4.11 The steel bar yield strength control chart for the 11th week.

The figure below shows the steel bar yield strength control chart at the 12th week, where sample no 6, 11, 12, 25 and 26 does not conform the specification limits.

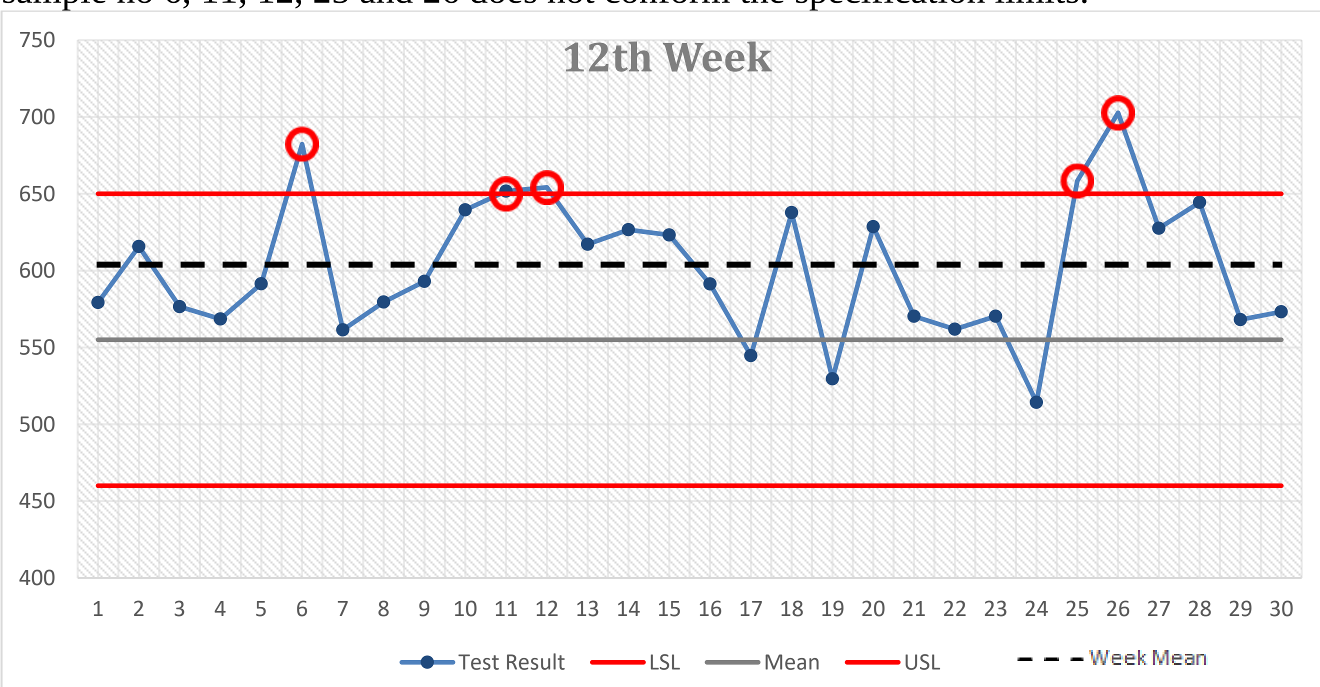

Fig 4.12 The steel bar yield strength control chart for the 12th week.

4.3. The Increase of nonconformities by time:

In this study the steel bar produced by Giad Iron Industries is evaluated using statistical quality control methods, and ASTM615.

As stated by ASTM615 the USL is 460, and LSL is 650, the result show that at the first weeks there is view points out of control that increased by time as shown in the last weeks, where the highest out of control point shown in the 9th week, that indicate the machine deterioration by the time.

The most of out of control chart that, where above the USL unless there is three points lower LSL, they occurred at 4th week.

Also, the study observed that out of control points during the week is occurred at series manner as shown in fig , which is indicate the reason of cause is symmetric.

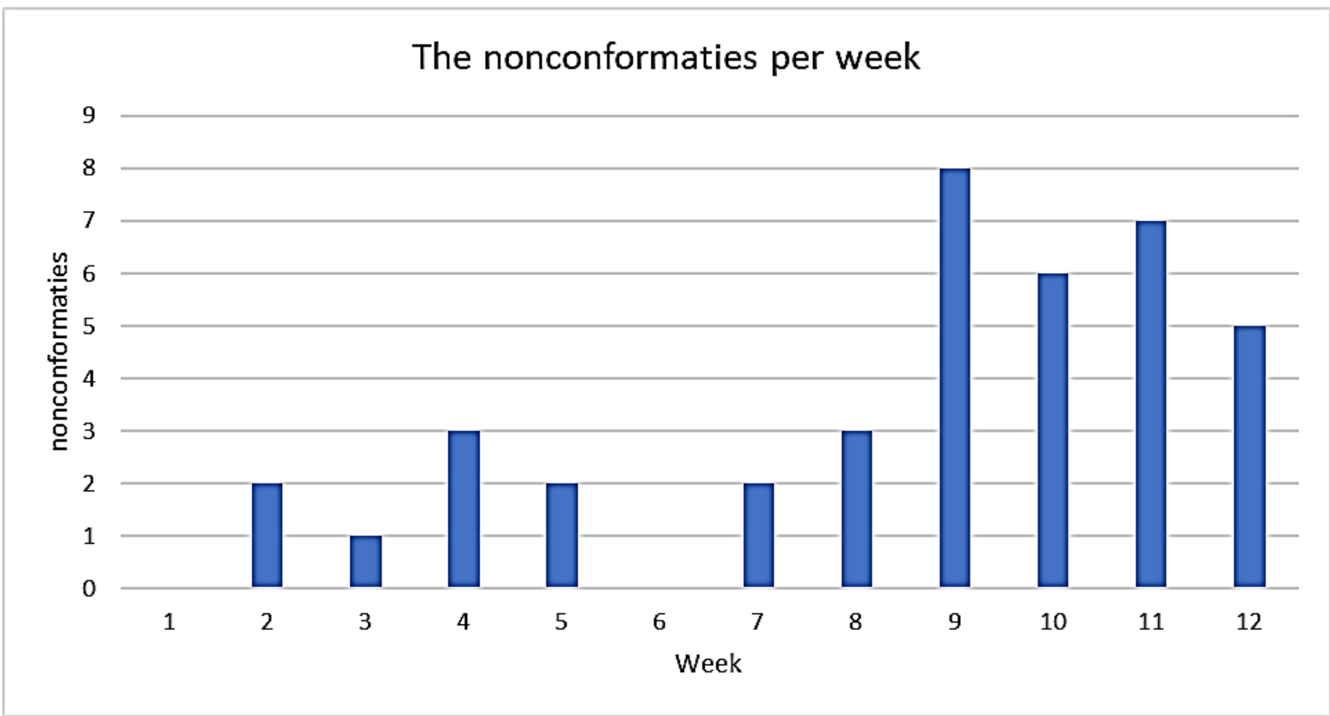

Fig 4.12 The nonconformities per week for 12th successive week for yield strength of Giad iron industries steel bar.

4.4. The Capability analysis for yield strength of Giad iron industries steel bar:

The capability analysis show that the process not capable to produce within control limit, and that due to the shift of the process to the upper control limit.

The properties of steel bar specially the tensile strength is required to be as high as possible to resist the tension load.

But due the quality specifications the variance should be reduced, and so on the out of control points should be evaluated.

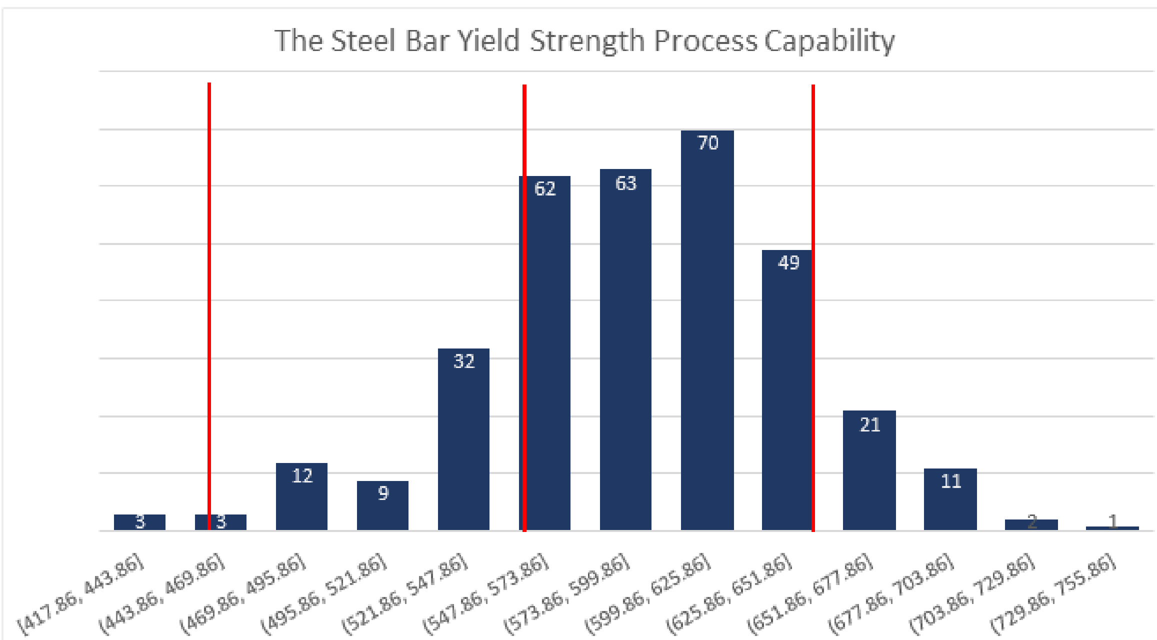

Fig 4.13 The steel bar yield strength Process Capability.

$$C_{pk} = \text{Minimum}\ (C_{pu}, C_{pl})$$

$$C_{pk} = \text{Minimum}\left\{\frac{USL-\mu}{3\sigma}, \frac{\mu-LSL}{3\sigma}\right\}$$

$$C_{pk} = \text{Minimum}\left\{\frac{650-591.8}{3*50.9}, \frac{591.8-460}{3*50.9}\right\}$$

$$C_{pk} = \text{Minimum}\{0.3806, 0.8627\}$$

$$C_{pk} = 0.3806$$

If is $C_{pk} \geq 5$ then the process under control.

Where:

C_{pk}: Capability Ratio.

C_{pu} : Capability Ratio for upper specification limit.

C_{pu} : Capability Ratio for lower specification limit.

C_{pk} = Minimum (C_{pu}, C_{pl})

= Minimum (0.3806, 0.8627) = 0.3806

Then the process not capable to produce within control limit

CHAPTER FIVE: CONCLUSION & RECOMMENDATIONS

5. Conclusion & Recommendations:

5.1. Conclusion:

The Giad iron industry steel bar evaluated aiming to state the area of thread in case of violation, this done by using ASTM 615 standard method, and with aim of control charts and using the process capability analysis the process analyzed. The tensile test is used as the quality characteristic, which is most desired specification in purpose of usage. The results shown the process shift to the right-hand side in process capability analysis, and out of control points at upper side in control charts, which increased by time. The violation of point at upper side it means the high tensile strength more than standard specification, and it could not cause the problem in case of using, but due to the mean of quality reducing the variance its consider out of control process, and not capable to produce within control limit.

5.2. Recommendation

For the next researcher in this field, it recommends that to do comparative study between Giad iron industry streel bar quality and other steel bar of other industry that produced in Sudan.

For the Giad iron industry of steel bar, it recommends that to enhance the log of each tasks, which ease the process of analysis and easily find the area of the threads. Also alter the process to decrease the variance and put the process under control by keeping the specification.

REFERENCES

6. References

[1] M. P. Groover, Fundamentals of Modern Manufacturing Materials, Processes, and Systems, Wiley.

[2] ASTM, "Standard Specification forDeformed and Plain Carbon Steel Bars for ConcreteReinforcement," 2003.

[3] E. A.-E. Taghried Isam Mohammed Abdel-Magid 1 *, "Quality Evaluation Of Steel Reinforcement Bars In Khartoum State," *Red sea university Journal of Basic and Applied Science*, vol. II, 2017.

[4] K. R. P. H. A. A. Ignatius C. Okafor, "Producing A615 / A615M High Strength Construction Re-Bars Without Use ofMicroalloys: Part 2," *Mechanics, Materials Science & Engineering*, no. 2412-5954, 2015.

[5] D. E. S. A. O. S. Sanmbo Balogun, "Challenges of Producing Quality Construction Steel Bars in West Africa:Case Study of Nigeria Steel Industry," *Minerals & Materials Characterization & Engineering*, vol. 8, pp. 283-292, 2009.

7. Appendixes:

7.1. The Yield strength for the successive 12th week, obtained in Giad iron industry of steel bar. Which used in the study.

	Yield Strength				
	Test Result	LSL	Mean	USL	Week Mean
1st week	587.13	460	555	650	602
	593.95	460	555	650	602
	605.1	460	555	650	602
	639.26	460	555	650	602
	592.81	460	555	650	602
	574.12	460	555	650	602
	631.92	460	555	650	602
	593.8	460	555	650	602
2nd Week	568.07	460	555	650	617
	607.02	460	555	650	617
	665.8	460	555	650	617
	644.13	460	555	650	617
	644.61	460	555	650	617
	638.24	460	555	650	617
	595.44	460	555	650	617
	627.33	460	555	650	617
	578.12	460	555	650	617
	618.37	460	555	650	617
	599.86	460	555	650	617
	613.23	460	555	650	617
	591.38	460	555	650	617
	606.95	460	555	650	617
	593.87	460	555	650	617
	598.94	460	555	650	617
	617.01	460	555	650	617
	613.82	460	555	650	617
	587.44	460	555	650	617
	606.58	460	555	650	617
	641.19	460	555	650	617
	660.62	460	555	650	617
	594.44	460	555	650	617
	608.73	460	555	650	617

	617.98	460	555	650	617
	611.81	460	555	650	617
	621.09	460	555	650	617
	644.72	460	555	650	617
	641.1	460	555	650	617
	647.36	460	555	650	617
3rd Week	603.35	460	555	650	573
	591.2	460	555	650	573
	637.69	460	555	650	573
	607.64	460	555	650	573
	624.74	460	555	650	573
	616.94	460	555	650	573
	643.34	460	555	650	573
	627.8	460	555	650	573
	609.13	460	555	650	573
	587.04	460	555	650	573
	668.74	460	555	650	573
	619.58	460	555	650	573
	635.62	460	555	650	573
	616.17	460	555	650	573
	623	460	555	650	573
	613.34	460	555	650	573
	628.85	460	555	650	573
	644.56	460	555	650	573
	632.82	460	555	650	573
	623.52	460	555	650	573
	641.15	460	555	650	573
	620.38	460	555	650	573
	619.8	460	555	650	573
	628.97	460	555	650	573
	618.46	460	555	650	573
	642.32	460	555	650	573
	617.43	460	555	650	573
	599.89	460	555	650	573
	552.96	460	555	650	573
	599.74	460	555	650	573
4th Week	619.34	460	555	650	525
	618.88	460	555	650	525
	604.13	460	555	650	525
	635.03	460	555	650	525

	604.13	460	555	650	525
	577.74	460	555	650	525
	606.82	460	555	650	525
	417.86	460	555	650	525
	417.86	460	555	650	525
	484.43	460	555	650	525
	486.74	460	555	650	525
	541.4	460	555	650	525
	492.81	460	555	650	525
	479.75	460	555	650	525
	476.22	460	555	650	525
	442.07	460	555	650	525
	492.62	460	555	650	525
	479.82	460	555	650	525
	569.84	460	555	650	525
	548.39	460	555	650	525
	541.73	460	555	650	525
	565.7	460	555	650	525
	528.26	460	555	650	525
	493.13	460	555	650	525
	525.63	460	555	650	525
	512.43	460	555	650	525
	492.69	460	555	650	525
	504.94	460	555	650	525
	502.11	460	555	650	525
	492.69	460	555	650	525
5th Week	505	460	555	650	557
	469.31	460	555	650	557
	462.75	460	555	650	557
	579.68	460	555	650	557
	534.93	460	555	650	557
	533.35	460	555	650	557
	522.62	460	555	650	557
	553.6	460	555	650	557
	544.13	460	555	650	557
	545.67	460	555	650	557
	544.61	460	555	650	557
	565.29	460	555	650	557
	547.26	460	555	650	557
	562.44	460	555	650	557

	558.31	460	555	650	557
	551.02	460	555	650	557
	539.31	460	555	650	557
	583.44	460	555	650	557
	565.39	460	555	650	557
	565.18	460	555	650	557
	469.64	460	555	650	557
	521.82	460	555	650	557
	618.49	460	555	650	557
	664.28	460	555	650	557
	600.28	460	555	650	557
	685.27	460	555	650	557
	533	460	555	650	557
	552.6	460	555	650	557
	612.74	460	555	650	557
	619.92	460	555	650	557
6th Week	557.03	460	555	650	563
	537.8	460	555	650	563
	598.56	460	555	650	563
	576.46	460	555	650	563
	571.5	460	555	650	563
	582.34	460	555	650	563
	571	460	555	650	563
	580.94	460	555	650	563
	583.34	460	555	650	563
	584.16	460	555	650	563
	564.07	460	555	650	563
	557.71	460	555	650	563
	559.25	460	555	650	563
	545.99	460	555	650	563
	573.35	460	555	650	563
	581.42	460	555	650	563
	554.02	460	555	650	563
	563.3	460	555	650	563
	553.42	460	555	650	563
	543.28	460	555	650	563
	546.32	460	555	650	563
	577.7	460	555	650	563
	552.86	460	555	650	563
	551.44	460	555	650	563

	556.88	460	555	650	563
	504.17	460	555	650	563
	549.67	460	555	650	563
	535.47	460	555	650	563
	615.61	460	555	650	563
	554.55	460	555	650	563
7th Week	571	460	555	650	584
	555.78	460	555	650	584
	556.12	460	555	650	584
	531.37	460	555	650	584
	571.26	460	555	650	584
	551.69	460	555	650	584
	599.54	460	555	650	584
	596.99	460	555	650	584
	529.35	460	555	650	584
	489.45	460	555	650	584
	672.96	460	555	650	584
	659.19	460	555	650	584
	595.32	460	555	650	584
	545.97	460	555	650	584
	627.64	460	555	650	584
	569.33	460	555	650	584
	590.33	460	555	650	584
	586.42	460	555	650	584
	605.54	460	555	650	584
	586.42	460	555	650	584
	605.54	460	555	650	584
	578.9	460	555	650	584
	533.2	460	555	650	584
	522.89	460	555	650	584
	628.29	460	555	650	584
	598.67	460	555	650	584
	634.3	460	555	650	584
	566.93	460	555	650	584
	608.15	460	555	650	584
	640.02	460	555	650	584
8th Week	616.51	460	555	650	601
	600.76	460	555	650	601
	593.3	460	555	650	601
	620.53	460	555	650	601

	587.12	460	555	650	601
	643.69	460	555	650	601
	647.69	460	555	650	601
	549.77	460	555	650	601
	547.25	460	555	650	601
	595.73	460	555	650	601
	593.52	460	555	650	601
	595.14	460	555	650	601
	591.96	460	555	650	601
	623.47	460	555	650	601
	572.09	460	555	650	601
	654.58	460	555	650	601
	672.98	460	555	650	601
	615.25	460	555	650	601
	572.61	460	555	650	601
	562.67	460	555	650	601
	521.61	460	555	650	601
	531.7	460	555	650	601
	541.4	460	555	650	601
	587.91	460	555	650	601
	635.38	460	555	650	601
	653.44	460	555	650	601
	613.1	460	555	650	601
	647.3	460	555	650	601
	615.2	460	555	650	601
	618.8	460	555	650	601
9th Week	683.42	460	555	650	611
	682.05	460	555	650	611
	590.06	460	555	650	611
	624.74	460	555	650	611
	584.74	460	555	650	611
	659.92	460	555	650	611
	662.81	460	555	650	611
	634.34	460	555	650	611
	658.47	460	555	650	611
	703.53	460	555	650	611
	570.59	460	555	650	611
	640.5	460	555	650	611
	675.54	460	555	650	611
	683.78	460	555	650	611

	522.07	460	555	650	611
	564.75	460	555	650	611
	580.87	460	555	650	611
	591.65	460	555	650	611
	577.4	460	555	650	611
	588.24	460	555	650	611
	610.5	460	555	650	611
	622.53	460	555	650	611
	516.84	460	555	650	611
	555.98	460	555	650	611
	567.81	460	555	650	611
	608.18	460	555	650	611
	609.21	460	555	650	611
	587.56	460	555	650	611
	591.38	460	555	650	611
	580.39	460	555	650	611
10th Week	654.32	460	555	650	607
	617.74	460	555	650	607
	558.95	460	555	650	607
	658.87	460	555	650	607
	603.19	460	555	650	607
	636.74	460	555	650	607
	654.03	460	555	650	607
	614.73	460	555	650	607
	626.73	460	555	650	607
	620.03	460	555	650	607
	626.11	460	555	650	607
	561.2	460	555	650	607
	612.48	460	555	650	607
	677.98	460	555	650	607
	734.4	460	555	650	607
	606.94	460	555	650	607
	721.71	460	555	650	607
	546.33	460	555	650	607
	556.84	460	555	650	607
	552.11	460	555	650	607
	572.92	460	555	650	607
	593.33	460	555	650	607
	600.86	460	555	650	607
	569.55	460	555	650	607

	560.05	460	555	650	607
	566.76	460	555	650	607
	583.28	460	555	650	607
	560.95	460	555	650	607
	548.14	460	555	650	607
	611.91	460	555	650	607
11th Week	631.22	460	555	650	621
	544.65	460	555	650	621
	586.35	460	555	650	621
	631.05	460	555	650	621
	489.68	460	555	650	621
	692.91	460	555	650	621
	626.35	460	555	650	621
	619.04	460	555	650	621
	608.65	460	555	650	621
	672.55	460	555	650	621
	640.78	460	555	650	621
	666.93	460	555	650	621
	655.18	460	555	650	621
	611.52	460	555	650	621
	611.88	460	555	650	621
	620.21	460	555	650	621
	645.74	460	555	650	621
	637.97	460	555	650	621
	606.76	460	555	650	621
	648.46	460	555	650	621
	565.08	460	555	650	621
	592.24	460	555	650	621
	583.78	460	555	650	621
	593.97	460	555	650	621
	546.56	460	555	650	621
	573.58	460	555	650	621
	679.15	460	555	650	621
	629.42	460	555	650	621
	709.29	460	555	650	621
	697.22	460	555	650	621
12th Week	579.22	460	555	650	603
	615.68	460	555	650	603
	576.48	460	555	650	603
	568.55	460	555	650	603

	591.4	460	555	650	603
	682.32	460	555	650	603
	561.47	460	555	650	603
	579.5	460	555	650	603
	592.95	460	555	650	603
	639.54	460	555	650	603
	651.68	460	555	650	603
	654.18	460	555	650	603
	617.08	460	555	650	603
	626.58	460	555	650	603
	623.18	460	555	650	603
	591.31	460	555	650	603
	544.63	460	555	650	603
	637.74	460	555	650	603
	529.53	460	555	650	603
	628.62	460	555	650	603
	570.25	460	555	650	603
	561.79	460	555	650	603
	570.25	460	555	650	603
	514.27	460	555	650	603
	658.41	460	555	650	603
	702.73	460	555	650	603
	627.53	460	555	650	603
	644.41	460	555	650	603
	568.13	460	555	650	603
	573.22	460	555	650	603

7.2. The following pages contains the ASTM A615 standard.

Designation: A 615/A 615M – 04a

American Association State Highway and
Transportation Officials Standard
AASHTO No.: M 31

Standard Specification for Deformed and Plain Carbon Steel Bars for Concrete Reinforcement[1]

This standard is issued under the fixed designation A 615/A 615M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification covers deformed and plain carbon steel bars for concrete reinforcement in cut lengths and coils. Steel bars containing alloy additions, such as with the AISI and SAE series of alloy steels, are permitted if the resulting product meets all the other requirements of this specification. The standard sizes and dimensions of deformed bars and their number designations are given in Table 1. The text of this specification references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the specification.

1.2 Bars are of three minimum yield levels: namely, 40 000 [280 MPa], 60 000 [420 MPa], and 75 000 psi [520 MPa], designated as Grade 40 [280], Grade 60 [420], and Grade 75 [520], respectively.

1.3 Hot-rolled plain rounds, in sizes up to and including 2 in. [50.8 mm] in diameter in coils or cut lengths, when specified for dowels, spirals and structural ties or supports shall be furnished under this specification in Grade 40 [280], Grade 60 [420], and Grade 75 [520]. For ductility properties (elongation and bending), test provisions of the nearest smaller nominal diameter deformed bar size shall apply. Requirements providing for deformations and marking shall not be applicable.

NOTE 1—Welding of the material in this specification should be approached with caution since no specific provisions have been included to enhance its weldability. When steel is to be welded, a welding procedure suitable for the chemical composition and intended use or service should be used. The use of the latest edition of ANSI/AWS D 1.4 is recommended. This document describes the proper selection of the filler metals, preheat/interpass temperatures, as well as, performance and procedure qualification requirements.

1.4 This specification is applicable for orders in either inch-pound units (as Specification A 615) or in SI units (as Specification A 615M).

1.5 The values stated in either inch-pound units or SI units are to be regarded as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 6/A 6M Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling
A 370 Test Methods and Definitions for Mechanical Testing of Steel Products
A 510 Specification for General Requirements for Wire Rods and Coarse Round Wire, Carbon Steel
A 510M Specification for General Requirements for Wire Rods and Coarse Round Wire, Carbon Steel (Metric)
A 700 Practices for Packaging, Marking, and Loading Methods for Steel Products for Domestic Shipment
A 706/A 706M Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement
E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

2.2 *AWS Standard:*

ANSI/AWS D 1.4 Structural Welding Code—Reinforcing Steel[3]

2.3 *U.S. Military Standards:*

MIL-STD-129 Marking for Shipment and Storage[4]
MIL-STD-163 Steel Mill Products Preparation for Shipment and Storage[4]

2.4 *U.S. Federal Standard:*

Fed. Std. No. 123 Marking for Shipment (Civil Agencies)[4]

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.05 on Steel Reinforcement.

Current edition approved May 1, 2004. Published May 2004. Originally approved in 1968. Last previous edition approved in 2004 as A 615/A 615M – 04.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, FL 33135.

[4] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

***A Summary of Changes section appears at the end of this standard.**

TABLE 1 Deformed Bar Designation Numbers, Nominal Weights [Masses], Nominal Dimensions, and Deformation Requirements

Bar Designation No.[A]	Nominal Weight, lb/ft [Nominal Mass, kg/m]	Nominal Dimensions[B]			Deformation Requirements, in. [mm]		
		Diameter, in. [mm]	Cross-Sectional Area, in.^{2} [mm^2]	Perimeter, in. [mm]	Maximum Average Spacing	Minimum Average Height	Maximum Gap (Chord of 12.5 % of Nominal Perimeter)
3 [10]	0.376 [0.560]	0.375 [9.5]	0.11 [71]	1.178 [29.9]	0.262 [6.7]	0.015 [0.38]	0.143 [3.6]
4 [13]	0.668 [0.994]	0.500 [12.7]	0.20 [129]	1.571 [39.9]	0.350 [8.9]	0.020 [0.51]	0.191 [4.9]
5 [16]	1.043 [1.552]	0.625 [15.9]	0.31 [199]	1.963 [49.9]	0.437 [11.1]	0.028 [0.71]	0.239 [6.1]
6 [19]	1.502 [2.235]	0.750 [19.1]	0.44 [284]	2.356 [59.8]	0.525 [13.3]	0.038 [0.97]	0.286 [7.3]
7 [22]	2.044 [3.042]	0.875 [22.2]	0.60 [387]	2.749 [69.8]	0.612 [15.5]	0.044 [1.12]	0.334 [8.5]
8 [25]	2.670 [3.973]	1.000 [25.4]	0.79 [510]	3.142 [79.8]	0.700 [17.8]	0.050 [1.27]	0.383 [9.7]
9 [29]	3.400 [5.060]	1.128 [28.7]	1.00 [645]	3.544 [90.0]	0.790 [20.1]	0.056 [1.42]	0.431 [10.9]
10 [32]	4.303 [6.404]	1.270 [32.3]	1.27 [819]	3.990 [101.3]	0.889 [22.6]	0.064 [1.63]	0.487 [12.4]
11 [36]	5.313 [7.907]	1.410 [35.8]	1.56 [1006]	4.430 [112.5]	0.987 [25.1]	0.071 [1.80]	0.540 [13.7]
14 [43]	7.65 [11.38]	1.693 [43.0]	2.25 [1452]	5.32 [135.1]	1.185 [30.1]	0.085 [2.16]	0.648 [16.5]
18 [57]	13.60 [20.24]	2.257 [57.3]	4.00 [2581]	7.09 [180.1]	1.58 [40.1]	0.102 [2.59]	0.864 [21.9]

[A]Bar numbers are based on the number of eighths of an inch included in the nominal diameter of the bars [bar numbers approximate the number of millimetres of the nominal diameter of the bar].

[B]The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same weight [mass] per foot [metre] as the deformed bar.

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *deformed bar, n*—steel bar with protrusions; a bar that is intended for use as reinforcement in reinforced concrete construction.

3.1.1.1 *Discussion*—The surface of the bar is provided with lugs or protrusions that inhibit longitudinal movement of the bar relative to the concrete surrounding the bar in such construction. The lugs or protusions conform to the provisions of this specification.

3.1.2 *deformations, n*—protrusions on a deformed bar.

3.1.3 *plain bar, n*—steel bar without protrusions.

3.1.4 *rib, n*—longitudinal protrusion on a deformed bar.

4. Ordering Information

4.1 It shall be the responsibility of the purchaser to specify all requirements that are necessary for material ordered to this specification. Such requirements shall include but are not limited to the following:

4.1.1 Quantity (weight) [mass],

4.1.2 Name of the material (deformed and plain carbon steel bars for concrete reinforcement),

4.1.3 Size,

4.1.4 Cut lengths or coils,

4.1.5 Deformed or plain,

4.1.6 Grade,

4.1.7 Packaging (see Section 21),

4.1.8 ASTM designation and year of issue, and

4.1.9 Certified mill test reports (if desired). (See Section 16.)

5. Material and Manufacture

5.1 The bars shall be rolled from properly identified heats of mold cast or strand cast steel using the electric-furnace, basic-oxygen, or open-hearth process.

6. Chemical Composition

6.1 An analysis of each heat of steel shall be made by the manufacturer from test samples taken preferably during the pouring of the heats. The percentages of carbon, manganese, phosphorus, and sulfur, shall be determined. The phosphorus content thus determined shall not exceed 0.06 %.

6.2 A product check, for phosphorus, made by the purchaser shall not exceed that specified in 6.1 by more than 25 %.

7. Requirements for Deformations

7.1 Deformations shall be spaced along the bar at substantially uniform distances. The deformations on opposite sides of the bar shall be similar in size, shape, and pattern.

7.2 The deformations shall be placed with respect to the axis of the bar so that the included angle is not less than 45°. Where the line of deformations forms an included angle with the axis of the bar from 45 to 70° inclusive, the deformations shall alternately reverse in direction on each side, or those on one side shall be reversed in direction from those on the opposite side. Where the line of deformations is over 70°, a reversal in direction shall not be required.

7.3 The average spacing or distance between deformations on each side of the bar shall not exceed seven tenths of the nominal diameter of the bar.

7.4 The overall length of deformations shall be such that the gap (measured as a chord) between the ends of the deformations on opposite sides of the bar shall not exceed 12½ % of the nominal perimeter of the bar. Where the ends terminate in a longitudinal rib, the width of the longitudinal rib shall be considered the gap. Where more than two longitudinal ribs are involved, the total width of all longitudinal ribs shall not exceed 25 % of the nominal perimeter of the bar; furthermore, the summation of gaps shall not exceed 25 % of the nominal perimeter of the bar. The nominal perimeter of the bar shall be 3.1416 times the nominal diameter.

7.5 The spacing, height, and gap of deformations shall conform to the requirements prescribed in Table 1.

8. Measurements of Deformations

8.1 The average spacing of deformations shall be determined by measuring the length of a minimum of 10 spaces and dividing that length by the number of spaces included in the measurement. The measurement shall begin from a point on a deformation at the beginning of the first space to a corresponding point on a deformation after the last included space.

Spacing measurments shall not be made over a bar area containing bar marking symbols involving letters or numbers.

8.2 The average height of deformations shall be determined from measurements made on not less than two typical deformations. Determinations shall be based on three measurements per deformation, one at the center of the overall length and the other two at the quarter points of the overall length.

8.3 Insufficient height, insufficient circumferential coverage, or excessive spacing of deformations shall not constitute cause for rejection unless it has been clearly established by determinations on each lot (Note 2) tested that typical deformation height, gap, or spacing do not conform to the minimum requirements prescribed in Section 7. No rejection shall be made on the basis of measurements if fewer than ten adjacent deformations on each side of the bar are measured.

NOTE 2—As used within the intent of 8.3, the term "lot" shall mean all the bars of one bar size and pattern of deformations contained in an individual shipping release or shipping order.

9. Tensile Requirements

9.1 The material, as represented by the test specimens, shall conform to the requirements for tensile properties prescribed in Table 2.

9.2 The yield point or yield strength shall be determined by one of the following methods:

9.2.1 The yield point shall be determined by drop of the beam or halt in the gage of the testing machine.

9.2.2 Where the steel tested does not have a well-defined yield point, the yield strength shall be determined by reading the stress corresponding to the prescribed strain using an autographic diagram method or an extensometer as described in Test Methods and Definitions A 370. The strain shall be 0.5 % of gage length for Grade 40 [280] and Grade 60 [420] and shall be 0.35 % of gage length for Grade 75 [520]. When material is furnished in coils, the test sample shall be straightened prior to placing it in the jaws of the tensile machine. Straightening shall be done carefully to avoid formation of local sharp bends and to minimize cold work. Insufficient straightening prior to attaching the extensometer can result in lower-than-actual yield strength readings.

9.3 The percentage of elongation shall be as prescribed in Table 2.

TABLE 2 Tensile Requirements

	Grade 40 [280]A	Grade 60 [420]	Grade 75 [520]B
Tensile strength, min, psi [MPa]	60 000 [420]	90 000 [620]	100 000 [690]
Yield strength, min, psi [MPa]	40 000 [280]	60 000 [420]	75 000 [520]
Elongation in 8 in. [203.2 mm], min, %:			
Bar Designation No.			
3 [10]	11	9	. . .
4, 5 [13, 16]	12	9	. . .
6 [19]	12	9	7
7, 8 [22, 25]	. . .	8	7
9, 10, 11 [29, 32, 36]	. . .	7	6
14, 18 [43, 57]	. . .	7	6

A Grade 40 [280] bars are furnished only in sizes 3 through 6 [10 through 19].
B Grade 75 [520] bars are furnished only in sizes 6 through 18 [19 through 57].

10. Bending Requirements

10.1 The bend-test specimen shall withstand being bent around a pin without cracking on the outside radius of the bent portion. The requirements for degree of bending and sizes of pins are prescribed in Table 3. When material is furnished in coils, the test sample shall be straightened prior to placing it in the bend tester.

10.2 The bend test shall be made on specimens of sufficient length to ensure free bending and with apparatus which provides:

10.2.1 Continuous and uniform application of force throughout the duration of the bending operation.

10.2.2 Unrestricted movement of the specimen at points of contact with the apparatus and bending around a pin free to rotate.

10.2.3 Close wrapping of the specimen around the pin during the bending operation.

10.3 It is permissible to use more severe methods of bend testing, such as placing a specimen across two pins free to rotate and applying the bending force with a fixed pin. When failures occur under more severe methods, retests shall be permitted under the bend-test method prescribed in 10.2.

11. Permissible Variation in Weight [Mass]

11.1 Deformed reinforcing bars shall be evaluated on the basis of nominal weight [mass]. The weight [mass] determined using the measured weight [mass] of the test specimen and rounding in accordance with Practice E 29, shall be at least 94 % of the applicable weight [mass] per unit length prescribed in Table 1. In no case shall overweight [excess mass] of any deformed bar be the cause for rejection. Weight [mass] variation for plain rounds shall be computed on the basis of permissible variation in diameter. For plain bars smaller than ⅜ in. [9.5 mm], use Specification A 510 [Specification A 510M]. For larger bars up to and including 2 in. [50.8 mm], use Specification A 6/A 6M.

12. Finish

12.1 The bars shall be free of detrimental surface imperfections.

12.2 Rust, seams, surface irregularities, or mill scale shall not be cause for rejection, provided the weight, dimensions, cross-sectional area, and tensile properties of a hand wire brushed test specimen are not less than the requirements of this specification.

12.3 Surface imperfections or flaws other than those specified in 12.2 shall be considered detrimental when specimens containing such imperfections fail to conform to either tensile

TABLE 3 Bend Test Requirements

Bar Designation No.	Pin Diameter for Bend TestsA		
	Grade 40 [280]	Grade 60 [420]	Grade 75 [520]
3, 4, 5 [10, 13, 16]	3½ *d* B	3½ *d*	. . .
6 [19]	5*d*	5*d*	5*d*
7, 8 [22, 25]	. . .	5*d*	5*d*
9, 10, 11 [29, 32, 36]	. . .	7*d*	7*d*
14, 18 [43, 57] (90°)	. . .	9*d*	9*d*

A Test bends 180° unless noted otherwise.
B *d* = nominal diameter of specimen.

or bending requirements. Examples include, but are not limited to, laps, seams, scabs, slivers, cooling or casting cracks, and mill or guide marks.

NOTE 3—Reinforcing bar intended for epoxy coating applications should have surfaces with a minimum of sharp edges to achieve proper cover. Particular attention should be given to bar marks and deformations where coating difficulties are prone to occur.

NOTE 4—Deformed bars destined to be mechanically-spliced or butt-welded may require a certain degree of roundness in order for the splices to adequately achieve strength requirements.

13. Number of Tests

13.1 For bar sizes No. 3 to 11 [10 to 36], inclusive, one tension test and one bend test shall be made of the largest size rolled from each heat. If, however, material from one heat differs by three or more designation numbers, one tension and one bend test shall be made from both the highest and lowest designation number of the deformed bars rolled.

13.2 For bar sizes Nos. 14 and 18 [43 and 57], one tension test and one bend test shall be made of each size rolled from each heat.

13.3 For all bar sizes one set of dimensional property tests including bar weight [mass] and spacing, height, and gap of deformations shall be made of each bar size rolled from each heat.

14. Retests

14.1 If any tensile property of any tension test specimen is less than that specified, and any part of the fracture is outside the middle third of the gage length, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

14.2 If the results of an original tension specimen fail to meet the specified minimum requirements and are within 2000 psi [14 MPa] of the required tensile strength, within 1000 psi [7 MPa] of the required yield point, or within two percentage units of the required elongation, a retest shall be permitted on two random specimens for each original tension specimen failure from the lot. Both retest specimens shall meet the requirements of this specification.

14.3 If a bend test fails for reasons other than mechanical reasons or flaws in the specimen as described in 14.5 and 14.6, a retest shall be permitted on two random specimens from the same lot. Both retest specimens shall meet the requirements of this specification. The retest shall be performed on test specimens that are at air temperature but not less than 60°F [16°C].

14.4 If a weight [mass] test fails for reasons other than flaws in the specimen as described in 14.6, a retest shall be permitted on two random specimens from the same lot. Both retest specimens shall meet the requirements of this specification.

14.5 If any test specimen fails because of mechanical reasons such as failure of testing equipment or improper specimen preparation, a replacement specimen shall be permitted.

14.6 If flaws are detected in a test specimen, either before or during the performance of the test, a replacement specimen shall be permitted from the same heat and bar size as the original.

15. Test Specimens

15.1 All mechanical tests shall be conducted in accordance with Test Methods and Definitions A 370 including Annex A9.

15.2 Tension test specimens shall be the full section of the bar as rolled. The unit stress determination shall be based on the nominal bar area.

15.3 The bend-test specimens shall be the full section of the bar as rolled.

16. Test Reports

16.1 When specified in the purchase order, the following information shall be reported on a per heat basis. Report additonal items as requested or desired.

16.1.1 Chemical analysis including carbon, manganese, phosphorus, and sulfur.

16.1.2 Tensile properties.

16.1.3 Bend test.

16.2 A Material Test Report, Certificate of Inspection, or similar document printed from or used in electronic form from an electronic data interchange (EDI) transmission shall be regarded as having the same validity as a counterpart printed in the certifier's facility. The content of the EDI transmitted document must meet the requirements of the invoked ASTM standard(s) and conform to any EDI agreement between the purchaser and the supplier. Notwithstanding the absence of a signature, the organization submitting the EDI transmission is responsible for the content of the report.

NOTE 5—The industry definition invoked here is: EDI is the computer to computer exchange of business information in a standard format such as ANSI ASC X12.

17. Inspection

17.1 The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests (except product analysis) and inspection, shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

17.2 *For Government Procurement Only*— Except as otherwise specified in the contract, the contractor is responsible for the performance of all inspection and test requirements specified herein. The contractor shall be permitted to use his own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless disapproved by the purchaser at the time of purchase. The purchaser shall have the right to perform any of the inspections and tests at the same frequency as set forth in this specification, where such inspections are deemed necessary to ensure that material conforms to prescribed requirements.

18. Rejection

18.1 Unless otherwise specified, any rejection based on tests made in accordance with 6.2, shall be reported to the manufacturer within five working days from the receipt of samples by the purchaser.

18.2 Material that shows injurious defects subsequent to its acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

19. Rehearing

19.1 Samples tested in accordance with 6.2 that represent rejected material shall be preserved for two weeks from the date rejection is reported to the manufacturer. In case of dissatisfaction with the results of the tests, the manufacturer shall have the right to make claim for a rehearing within that time.

20. Marking

20.1 When loaded for mill shipment, bars shall be properly separated and tagged with the manufacturer's heat or test identification number.

20.2 Each producer shall identify the symbols of his marking system.

20.3 All bars produced to this specification, except plain round bars which shall be tagged for grade, shall be identified by a distinguishing set of marks legibly rolled onto the surface of one side of the bar to denote in the following order:

20.3.1 *Point of Origin*—Letter or symbol established as the producer's mill designation.

20.3.2 *Size Designation*—Arabic number corresponding to bar designation number of Table 1.

20.3.3 *Type of Steel*—Letter *S* indicating that the bar was produced to this specification, or for Grade 60 [420] bars only, letters *S* and *W* indicating that the bar was produced to meet both Specifications A 615/A 615M and A 706/A 706M.

20.3.4 *Minimum Yield Designation*—For Grade 60 [420] bars, either the number *60* [*4*] or a single continuous longitudinal line through at least five spaces offset from the center of the bar side. For Grade 75 [520] bars, either the number *75* [*5*] or two continuous longitudinal lines through at least five spaces offset each direction from the center of the bar. (No marking designation for Grade 40 [280] bars.)

20.3.5 It shall be permissible to substitute: a metric size bar of Grade 280 for the corresponding inch-pound size bar of Grade 40, a metric size bar of Grade 420 for the corresponding inch-pound size bar of Grade 60, and a metric size bar of Grade 520 for the corresponding inch-pound size bar of Grade 75.

21. Packaging

21.1 When specified in the purchase order, packaging shall be in accordance with the procedures in Practices A 700.

21.2 *For Government Procurement Only*— When specified in the contract or order, and for direct procurement by or direct shipment to the U.S. government, material shall be preserved, packaged, and packed in accordance with the requirements of MIL-STD-163. The applicable levels shall be as specified in the contract. Marking for shipment of such material shall be in accordance with Fed. Std. No. 123 for civil agencies and MIL-STD-129 for military agencies.

22. Keywords

22.1 concrete reinforcement; deformations (protrusions); steel bars

SUMMARY OF CHANGES

Committee A01 has identified the location of the following changes to this standard since A 615/A 615M-04 that may impact the use of this standard. (Approved May 1, 2004)

(1) Added 16.2 and Note 5.

Committee A01 has identified the location of the following changes to this standard since A 615/A 615M-03a that may impact the use of this standard. (Approved Jan. 1, 2004)

(1) Revised the title.
(2) Revised 1.1, 4.1.2, and 5.1.
(3) Revised 10.3 to eliminate permissive language.

Committee A01 has identified the location of the following changes to this standard since A 615/A 615M-03 that may impact the use of this standard. (Approved June 10, 2003).

(1) Deleted Note 2.
(2) Revised 6.2.
(3) Revised 14.5.
(4) Revised 14.6.
(5) Revised 16.1.
(6) Revised 17.2.
(7) Revised 19.1.