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INSTITUTE OF ENGINEERING
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Study on Mechanical Properties of Reinforcement Bars Manufactured in Nepal
with respect to NS-191

by

Umesh Yadav

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Pulchowk Campus, Institute of Engineering
Lalitpur, Kathmandu
Nepal

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INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS
DEPARTMENT OF MECHANICAL ENGINEERING

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis report entitled “**Study on Mechanical Properties of Reinforcement Bars Manufactured in Nepal with respect to NS-191**” submitted by Umesh Yadav in partial fulfillment of the requirements for the degree of Master of Science in Renewable Energy Engineering.

Supervisor, Dr. Bhakta Bahadur Ale

Professor

Department of Mechanical Engineering

External Examiner, Er. Mani Ram Bhusal

Senior Divisional Mechanical Engineer

Ministry of Physical Infrastructure and Transport

Committee Chairperson, Dr. Nawraj Bhattra

Head

Department of Mechanical Engineering

Date:

ABSTRACT

The deformed bars are graded according to their specified yield strength. These are Fe415, Fe500, Fe500D and Fe550. CTD bars of grade more than Fe415 are scarcely available in market. However, TMT bars of Fe500 grade are easily available in market. Deformed bars are one of the mandatory product must have NS-191 certificate grant before commercial production. NS standard establishes minimum criteria for the mechanical properties of deformed bars. However, they do not set maximum limits nor do they address instances where properties may significantly exceed the standard. This project was carried out to investigate the status of mechanical properties of deformed bars manufactured in Nepal. The tested data and obtained statistics of different mechanical properties for the separate and combined data takes on an important practical significance and may be used in calibrating local specifications and design.

This thesis outlines the output of mechanical test results of grade Fe500 and Fe500D TMT bars. Total 745 numbers of TMT bar samples were collected and tested at NBSM mechanical testing laboratory. The tested samples were representing reference samples of FY 2073-74 and FY 2074-75 stored at NBSM. These samples were from nineteen different rolling mills and twenty-two different brands.

The COV values for yield strength, tensile strength and UTS/YS ratio were found below 5 percent. The value of COV for percentage elongation were found between 5 to 10 percent for different bar size. The mean yield strength and tensile strength was found 554.4 MPa, and 663.4 MPa respectively for Fe500 grade TMT bars. The mean yield strength and tensile strength for Fe500D grade was found 565.2 MPa and 678.1 MPa respectively. The mean value of percentage elongation and UTS/YS ratio for both grade were found 22% and 1.2 respectively. Higher range of variation were observed for Fe500 TMT bars than Fe500D grade. These variations were believed to be caused by varying rolling practices and quality control measures used by different manufacturers. Comparing tested data with NS standard indicates the mechanical properties of deformed bars manufactured in Nepal are well above set standard value and comply with product standard requirements.

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
BS-EN	British Standard European Norms
CBS	Central Bureau of Statistics
CME	Census of Manufacturing Establishment
CSA	Canadian Standards Association
CTD	Cold Twisted Deformed
FY	Fiscal Year
IS	Indian Standard
ISO	International Organization for Standardization
NBSM	Nepal Bureau of Standards and Metrology
NS	Nepal Standard
NZS	New Zealand Standards
RC	Reinforced Concrete
TMT	Thermo Mechanically Treated
UTS	Ultimate Tensile Stress
YS	Yield Stress

CHAPTER ONE: INTRODUCTION

1.1 Background

Census of Manufacturing Establishment (CME) carried out in the fiscal year 2011/12 by the Central Bureau of Statistics (CBS) has classified Metal industry into three different classes namely a) basic iron and steel, b) structural metal products, and c) forging, pressing and stamping of metal. Iron rod, steel rod, stainless steel, cast iron pipe, corrugated sheet etc. are some of the export items of the industry. The number of basic iron and steel industries in Nepal is 20 with employment of 4,917 persons (CME, 2012/13). The sub-sector output value is estimated to be NPR 31.0 billion and contributes the input value of NPR 27.34 billion with addition of about NPR 3.75 billion. The average installed capacity of the plants in this sub-sector is 113 Tons per Day (TPD) and average production is 63.7 TPD (GIZ/NEEP, 2012).

Nepal has become self-sufficient in iron and steel materials due to increased production from old industries which is expanding capacity and new industries joining the business. Annual demand of iron and steel currently stands at around 2 million tonnes and domestic producers are supplying the required quantity in the market. New investment in the industry is a result of increased development works, boom in the construction of houses and commercial buildings. Iron and steel demand has been increased by 10 percent annually (New Business Age, March 2017).

Almost 90 percent of raw materials are imported from India. The remaining comes from third countries. Nepal has been importing raw materials and other related materials to manufacture reinforcement bar. The country imported MS steel billet, a major raw material, worth Rs 459.5 million in the FY 2074/75.

Houses in the hilly regions were mostly constructed from bricks, mud and wood till a few years ago. However, people in these areas nowadays build houses using concrete and iron bars. Some earthquake affected people have reconstructed their homes with modern construction materials. However, the construction of government buildings, historical monuments and religious structures destroyed or damaged by earthquake is in the process to build up. Similarly, the development of unified housing in the quake affected districts has begun. Hence, the demand for iron and steel bars has increased.

About 10 % of buildings in Nepal are RC buildings. The construction of RC buildings only started after 1980; however the mushrooming number of RC construction was started only after 1990. Even though the RC construction was started in early 1980s, engineered construction was only felt after enforcement of building codes in 2006 and almost 70 % of existing RC buildings are either owner built constructions constructed with the help of contractors following by-laws or constructed as per the mandatory rules of thumbs as suggested by Nepal Building Code (NBC, 1994).

In structural design, uncertainties in loadings, design, and construction make it possible for load effects to be higher than computed and resistances to be lower than computed. Potential sources of these uncertainties include unforeseen loading conditions, changes in structure use, varying constructions tolerances and loadings, and material property variations. As a result, building codes and design specifications require the use of load factors greater than 1.0 and strength reduction factors less than 1.0 in design of structures. The purpose of these factors is to limit the probability of failure to an acceptably low level (Bournonville, et al., December 2004).

Under the category of material property variations, the variability of the physical and mechanical properties of reinforcing steel affects the performance of reinforced concrete structures. In Nepal, these properties have minimum requirements, as detailed by (NS:191, 2069).

This study is undertaken to evaluate the variability in the mechanical properties of reinforcing steel produced throughout the Nepal and to analyze the degree to which manufacturers satisfy the minimum requirements established by product national standard (NS:191, 2069). This study is conducted by collecting samples of Grade Fe500 and Fe500D TMT bars, testing these samples in mechanical testing laboratory, and statistically analyzing the test data obtained from test results.

1.2 Problem Statement

NS standards establish minimum criteria for the mechanical properties of all reinforcing steel produced in Nepal. However, they do not set maximum limits nor do they address instances where properties may significantly exceed the standards. With the exceptions of structures designed for seismic applications, designers use the minimum values in design without considering the true strength of the reinforced steel. This may be of

concern because member behavior can differ from the planned response if material properties are significantly higher than those used in the design. For instance, if the reinforcement is too strong in a reinforced concrete flexural member, it is said to be over-reinforced. If the member is over loaded, this can result in brittle failure, with the concrete crushing before the steel yields. For members subjected to several lateral loads, an increase in flexure strength can increase the induced shear forces on the member, also resulting in brittle failure (Andriono, 1986).

An understanding of the variability of steel properties is also useful in the development of statistically-based expressions for member strength, which are used in development of reliability-based strength-reduction factors in design codes. For these reasons, it is worth examining the actual values of the mechanical properties of the reinforcing steel as compared to those used in design.

The mechanical properties of reinforcing steel are controllable in the manufacturing process, but variations between manufacturers and between heats for the same manufacturers do exist. Results may be influenced by several factors including but not limited to the rate of loading, bar cross-sectional area, and variation in the chemical composition of steel. All reinforcing steel manufacturers must perform tests on their products to verify that they meet the (NS:191, 2069) Standard. These tests measured mass per meter run, yield strength, tensile strength, percentage elongation, bond value, bend test, re-bend test and total elongation at maximum force. Chemical analysis of the billet is also important parameter to comply as per product standard.

The statistical analysis of these tested samples data are conducted to evaluate the quality of the reinforcing steel in terms of these minimum NS standard. As part of analysis the fit line plot were checked and some equations are obtained from graph to show relationship between mechanical properties.

1.3 Scope of Thesis

Three grades of bars are presently available in Nepal for structural use. The deformed bars are graded according to their specified yield strength. These are Fe415, Fe500 and Fe500D. Cold twisted deformed (CTD) bars of grade more than Fe415 are scarcely available in market. However, TMT bars of Fe500 grade are easily available in the market. The common size of reinforcement bar being manufactured are 8 mm, 10 mm, 12 mm, 16 mm, 20 mm, 25 mm, 28 mm and 32 mm nominal diameter. The raw material,

prime billet mostly imported from India and very few from third countries with supplier test certificates of materials. The scope of this thesis include only mechanical testing of physical properties of reinforcement bars. The grades consider for this thesis work is Fe500 and Fe500D TMT bars only. In this thesis work, it is tried to include all the available sizes of reinforcement bar. However, most of the industries have granted the license for producing 8 mm to 32 mm size, they only produce common size of reinforcement bar and the bigger size is produced as per demand only. For this thesis work, all the samples are collected from the NBSM reference sample store room, where the reference samples are stored after the 35 days from the date of issue of test reports. Only mechanical properties of reinforcement bar fall in the scope of the thesis.

1.4 Research Objectives

1.4.1 Main Objective

To study on mechanical properties of reinforcement bars manufactured in Nepal with respect to NS-191.

1.4.2 Specific Objectives

- i. To determine mechanical properties: mass per meter run, yield strength, tensile strength, percentage elongation, UTS/YS ratio, bond value, total elongation at maximum force, bend test, and re-bend test.
- ii. To compare the mechanical test results with NS:191 requirements.
- iii. To examine statistical analysis of mechanical test results of reinforcement bars.

1.5 Limitation of Thesis

The product standard include the requirement of physical and chemical properties for different grades. Chemical analysis were not conducted on the collected samples. All the samples were taken from NBSM reference sample store room. The collected samples were the representative samples of FY 073-74 and FY 074-75 received at NBSM mechanical testing laboratory for testing purpose through sample management unit. Pull out test for bond test were not conducted due to unavailability of testing facility at NBSM and total elongation at maximum force were conducted only by manual method specified in test method. There were no facility available of using extensometer for total elongation at maximum force calculation.

CHAPTER TWO: LITERATURE REVIEW

2.1 Conceptual Framework

The variability of the mechanical properties of reinforcing steel is studied by several researchers. In 1972, the National Research Council (NRC) of Canada published the results of a study analyzing the mechanical properties of reinforcement steel (Allen, 1972). Two data samples were used, one consisting of 132 bars from Canadian manufacturing plant and the other consisting of tests by the NRC on 102 bars obtained from five separate heats. The NRC tests, performed using greater control than those specified by ASTM or CSA, provided information about the variations along a bar and from one bar to another within a heat. The manufacturing plant data provided information on the overall variability of reinforcing steel from one manufacturer. The results showed that the coefficient of variation increased as one move from one bar to a group of bars from the same heat and then to the entire plant. Additionally, a significant difference in the stress-strain curves was found to exist between No.3 and larger bars. The curves for No. 3 bars had no yield plateau, while that of the larger bars did. This difference was explained based on the possibility that the No. 3 bars had undergone cold working due to their smaller size.

Several properties were measured under two loading conditions: static and dynamic (standard). Allen (1972) felt that the static loading condition better reflected actual loading conditions, and he concluded that subtracting an empirically derived value from mill test results would provide the static yield stresses at which failure would occur in practice. He also acknowledged that the deviation could be reduced if CSA specifications were modified in the following ways: (1) the nominal bar area was used instead of the actual bar area in calculations of stress and (2) the maximum rate of loading was reduced. Allen concluded, however, that the current control methods for testing were adequate.

Mirza and MacGregor (1979) published a study that addressed the variability of mechanical properties of reinforcing steel (Mirza & Macgregor, 1979). In this study, variations in yield and tensile strength and in modulus of elasticity were examined. These variations were believed to be caused by varying rolling practices and quality control measures used by different manufacturers, as well as possible variation in cross-sectional area, steel strength, and rate of loading. The study was based on a sample of

3,947 bars taken from 13 sources, some published and some unpublished. Mirza and MacGregor (1979) found that the beta distribution could be used to represent the probability distributions for both yield and tensile strength. They also found that the data they used for each grade of steel could be closely represented with a normal distribution between about 5th and 95th percentile. At the lower end of the tail, their data dropped well below the normal distribution line for all grades evaluated. Conversely, data at the upper tail curved above the normal distribution line for Grade 40 yield strength and below the normal distribution line for Grade 60 yield strength and tensile strength.

Joshi and Ranganathan (1988) collected data on yield strength and modulus of elasticity of steel bars from different rolling mills and building sites and performed a statistical analysis of the same. They calculated the total variation of strength of steel bars and found that normal and log-normal distributions fit the data (Joshi & Ranganathan, May 1988).

Bournonville, Dahnke and Darwin (2004), evaluated the variability of the mechanical properties and weight of steel reinforcing bars produced in the United States and Canada under various ASTM standards. They conducted a statistical analysis on data from 29 mills and developed expressions to represent the probability distributions functions for yield and tensile strength, elongation and percentage of nominal weight. Trends in the data are evaluated based on grade, bar size and production mill. Both normal and Beta distribution functions for yield and tensile strength depending on bar size, grade and steel type, as well as for all bars for each grade and steel type. They gave some percentage for the steel heats that failed to meet minimum ASTM standards (Bournonville, et al., December 2004).

Tat (1991), investigated the distribution of mechanical properties for NZS 3402 Grade 300 and micro alloyed grade 340 reinforcing steel bars. For the both grade of steel distribution of lower yield strength, tensile strength, elongation at fracture, Luder strain at yield point, strain hardening parameters n and k , and the three parameters measuring strain aging index were determined. Multiple linear regression techniques were used to investigate relationship between the determined mechanical properties and the steel chemical composition. The regression analysis yielded simple linear equations which

can be used to predict the mechanical properties of bars from production on variation in chemical composition (Tat, June 1991).

Rai (2012), evaluated the properties of steel reinforcing bars for seismic design and found that for dependable flexure behavior, yield strength and ultimate tensile strength values should be lie in a narrow band around value used in the member design. If these values are greater than the specified value, it may cause brittle shear failure instead of more ductile and desirable flexure mode of failure. They conducted test on thirty beams to either failure or to the maximum displacement available with the actuator. They studied flexural strength, shear strength, failure mode and cracking pattern in the beams (Rai, et al., 2012).

Taher (2013), presented the conference paper addressed variability in yield strength and elongation of reinforcing steel bars. In that study, they conducted statistical analysis on the collected yield strength and elongation data of reinforcing steel bars obtained from different sources and tested at university laboratory. Probability distribution functions were developed to represent the yield strength and elongation tested data for each bar size, source, grade, as well as for combined bars (Ben Taher, et al., June 2013).

2.2 Literature Related to Materials

There are several processes of steel production which include; Electric Arc Steelmaking, Basic Oxygen Steelmaking, Open Hearth Process, etc. In the context of Nepal there is no any primary billet manufacturer industries at present. Almost 90 percent of raw materials are imported from India. The remaining comes from third countries. Nepal has been importing raw materials and other related materials to manufacture reinforcement bar. The country imported MS steel billet, a major raw material, worth Rs 459.5 million in the FY 2074/75. The per capita annual consumption of iron and steel products in advanced economies is 100 kg. In China, it is 200 kg, whereas in developing countries it is 50-60 kg. In India, the per capita consumption of iron and steel product is 60 kg. However, it is hardly 30 kg in Nepal (New Business Age, March 2017).

2.2.1 Information on Controlled Cooling Process

Information regarding controlled cooling process is described in Appendix B of NS:191. The process of reinforcing steel is usually through one or combination of

processes which may include hot rolling after micro-alloying, hot rolling followed by controlled cooling (TMT process) and hot rolling followed by cold work.

Heat treatment is a thermal process undergone by the steel in the solid state. The most common practice is finishing online heat treatment while rolling, commonly known as thermo-mechanical treatment (TMT) process. After leaving the last stand of the rolling mill, the bars are quenched (rapidly cooled) in water from a final rolling temperature of about 950°C. The quenching is partial, only until a surface layer has been formed from austenite (a steel phase stable only at very high temperature) to martensite (stable at temperature below 350°C). This controlled quenching is achieved in one or more online water cooling devices through which the steel passes at a very high speed before reaching the cooling bed.

Because the quenching is only partial, a part of the original heat remains in the core of the steel and, on the cooling bed, this heat migrates towards the surface. This results in an automatic self-tempering process where the surface layer of martensite is tempered; this 'tempering temperature' (or equalizing temperature) refers to maximum temperature attained by the bar surface after quenching. Tempering enables a partial diffusion of carbon out of the extremely brittle but strong martensite, thus relieving the inherent stresses locked in during the sudden quenching of the red hot steel in cold water. The resulting tempered- martensite shows improved deformability compared to the as-quenched martensite.

The core of the heat treated reinforced bars/wires consist of ferrite and perlite- more ductile but less strong than the martensite. Computerized process control is used to dynamically adjust the many rapidly changing parameters depending on the chemical composition of the steel, the desired grade and size of the reinforcing bar/wire etc. For the larger diameters, small addition of micro-alloys is usual (NS:191, 2069).

In the context of Nepal and other countries following two technologies are used for cooling process of reinforced deformed steel bars.

- a) THERMEX Process: It is a trademark name under Hennigsdorfer Stahl Engineering (HSE) Germany. Special importance was accorded to the development of a rapid water quenching system for the production of thermo-processed rebars to meet the exacting demands from civil designers in terms of

low costs and increased strength without additionally processes such as twisting. The THERMEX cooling system is a specially designed Thermex cooling pipes have been patented in a lot of countries. A short, intensive but very precise in-line cooling of the rolled bar is imparted in THERMEX process through proprietary system. This treatment results in a cooled hardened periphery. On further cooling of the bar in atmosphere a thermal exchange (THERMEX) occurs between the core and cooled outside martensite surface where by the resultant bar structure is a distinct tempered martensite at periphery and a fine grained ferrite- pearlite structure in the central zone. The different mechanical properties required by various standards are easily achieved by only adjusting the water quenching parameters.

- b) TEMPCORE Process: It is trade mark name under Centre de Recherches Metallurgiques (CRM), Belgium. In this process the re-bar leaving the last stand of hot rolling passes through a special cooling section. The cooling is such that a surface layer of the bar is quenched into martensite, the core remaining austenitic. The quenching treatment is stopped when a determined thickness of martensite has been formed under the skin. The re-bar leaves the drastic cooling section, the temperature gradient established in its cross section causes heat to flow from the center to the surface. This results in self tempering of martensite. Finally, during the slow cooling of the re-bar on cooling bed, austenitic core transforms into ferrite and pearlite. The temp core process is shown in Figure 2.1 below.

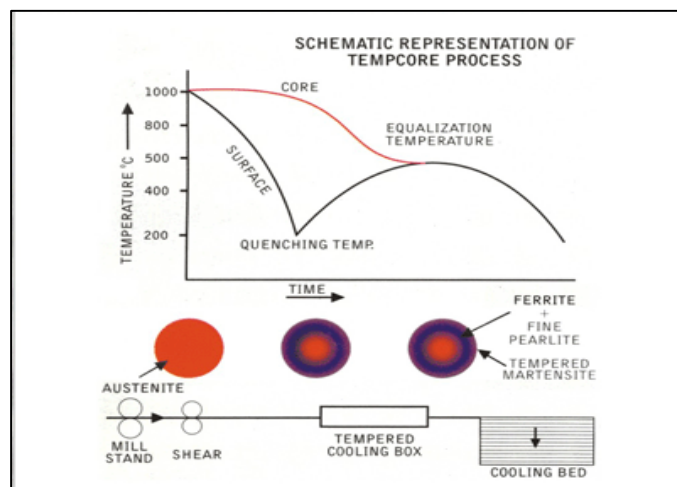


Figure 2.1 Schematic diagram of TEMPCORE process

(Source: <http://www.peakayrm.com/img/tempcore.gif>)

2.2.2 Influence of Chemical Ingredients

Carbon is the cheapest and one of the most effective alloying elements for hardening iron. The higher the carbon content the greater the hardenability of the steel and greater is the strength, hardness and wear resistance. However, ductility, weldability, and toughness are reduced with increasing carbon content (Kenneth & Dionisio, 1997). The presence of sulphur and phosphorus have negative effect on reinforcing steel if present above 0.05%. High sulphur content weakens the steel and could lead to the development of directional properties, reduction in weldability and increase in brittleness. The maximum recommended percent of sulphur in reinforcing steel is 0.05% (Allen, 1979). On the other hand, high phosphorus content in steel increases the tendency towards coarse grained steel with the attended reduction in strength. According to (Moore, 1997), the level of residual elements such as copper, manganese, etc. must be kept very low to avoid serious reduction in the mechanical properties of the steel.

Properties of reinforced bars are influenced by the chemical composition of the steel from which it is manufactured. Table 2.1 shows the influence of different chemical ingredients of steel on the properties of reinforced bars.

Table 2.1 Influence of different chemical ingredients in steel on properties of bar (Source: Basu, et al., 2004)

No	Chemicals	Effects on reinforced bars	
		Controlling property	Actual effect
1	Carbon (C)	Hardness, strength, weldability and brittleness	Higher carbon contributes to the tensile strength of steel, that is, higher load bearing capacity and vice versa. Lower carbon content less than 0.1 percent will reduce the strength. Higher carbon content of 0.3 percent and above makes the steel bar unweldable and brittle.
2	Manganese (Mn)	Strength and yield strength	The manganese content in steel is not specified as per (IS:1786, 2008). However higher manganese content in steel increases the tensile strength and also the carbon equivalent property.

3.	Sulphur (S)	Present as an impurity in steel which increases its brittleness	Presence of sulphur should be limited as per IS:1786. Presence of higher sulphur makes the bar brittle during twisting, as higher sulphur content brings the hot shot problem during rolling.
4	Phosphorus (P)	Present as an impurity which increases strength and brittleness	Higher phosphorus content contributes to the increase in strength and corrosion resistance properties but brings brittleness due to the formation of low euctoid phosphicles in the grain boundary. Also lower the impact value at sub zero temperature level (transition temperature).
5	Copper (Cu)	Strength and corrosion resistance properties	Being a pearlite stabiliser, it increases strength and corrosion resistance property.
6	Chromium (Cr)	Weldability and corrosion resistance	Present as an impurity from the scrap and influence carbon equivalent; weldability and increases corrosion resistance property.
7	Carbon Equivalent (CE or C_{eq})	Hardness, tensile strength and weldability	This property is required to set the cooling parameters in TMT process and a slight variation in carbon equivalent may alter the physical properties. In case of CTD bars, carbon equivalent has a maximum limit of 0.42 percent but there is no lower limit prescribed. As such, as long as the chemical composition and physical properties of raw materials are within specified limits, the variation in carbon equivalent as in the case of TMT bars.

CHAPTER THREE: RESEARCH METHODOLOGY

The calculation and testing of mechanical properties of reinforcement bars involve a set of procedure starting from sample collection to test results analysis as outlined in the following flowchart Figure 3.1. There are many different types of industries within metal sector in Nepal that includes both ferrous and non-ferrous metal industries. However, for the present study, mainly hot rolling mills has been considered as they are dominant in Nepal. The rolling mills use imported continuous cast billets to manufacture various diameters and length of deformed iron bars to be used for reinforcing concrete structure.

3.1 Flowchart of methodology adopted

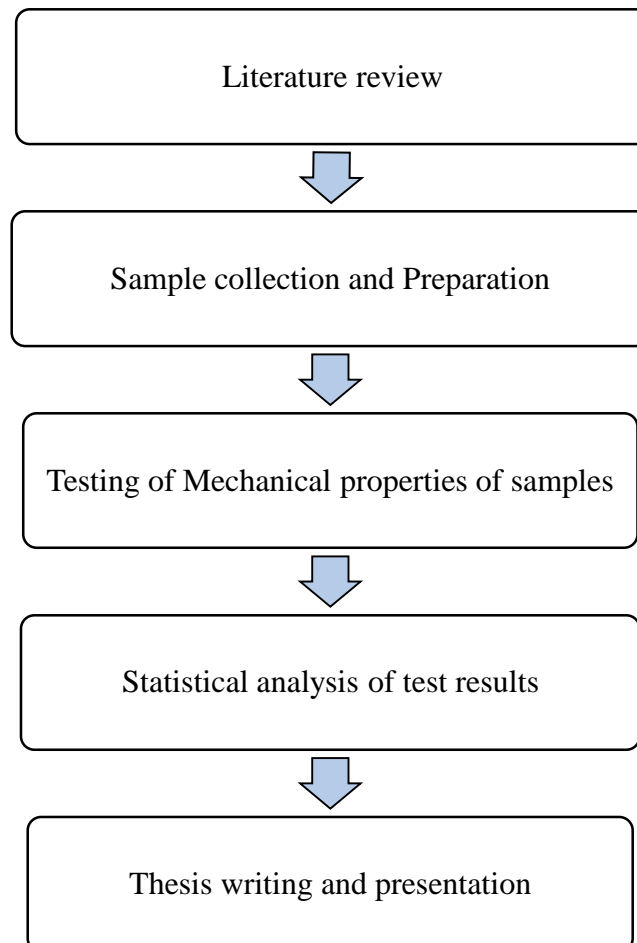


Figure 3.1 Flow chart of methodology adopted

3.2 Study of TMT bars

In the present study, mainly hot rolling mills has been considered as they are dominant in Nepal. The rolling mills use imported continuous cast billets to manufacture various diameters and length of iron bars to be used for reinforcing concrete structure. Three grades of bars are presently available in Nepal for structural use. The deformed bars are graded according to their specified yield strength. These are Fe415, Fe500 and Fe500D. Cold twisted deformed (CTD) bars of grade more than Fe415 are scarcely available in market. Also, CTD bar of Fe 415 is produced by only Himal steel at present. However, TMT bars of Fe500 grade are easily available in the market. The common size of reinforcement bar being manufactured are 8mm, 10mm, 12mm, 16mm, 20mm, 25mm, 28mm and 32mm nominal diameter. This study covers the TMT bar of Fe500 and Fe500D grades. The representative samples are selected which are available at NBSM mechanical testing sample reference room. No samples were collected from industry premises or market. The study covers samples of twenty two brands of nineteen industries granted with NS mark for their products.

3.3 Sample collection

There are basically two grades of reinforcing steel being tested in this thesis work, namely Fe500 TMT bars and Fe500D TMT bars.



Figure 3.2 Reference samples stored at NBSM mechanical testing laboratory

Nepal Bureau of Standard and Metrology (NBSM) is a national standard body for Nepal. This is a government organization under Ministry of Industry, Commerce and Supplies. It works on formulation of National Standards and Certification of manufacturing and service industries as per national standard. NBSM has good laboratory facility for testing different products manufactured under their product certification scheme. NBSM has mechanical testing laboratory, where, different types of mechanical products are tested. For this research work, samples are collected from NBSM reference sample store room shown in Figure 3.2. These reinforced bars are from FY 2073/74 and FY 2074/75. Samples are segregated from reference room as according to Grade Fe 500 and Fe 500D, brand name, and diameter of reinforced bars. Total 745 number of samples of 22 different brand was collected. Among them, 19 brand were Fe 500 TMT bars and 3 brands were Fe 500D grade TMT bars. The diameter of the collected samples were 8mm, 10mm, 12mm, 16mm, 20mm, 25mm, 28mm, and 32mm. To provide confidentiality to all manufacturers brand collected for this work, a short code name is assigned to all brand. The sample size of each grade of reinforcing steel are listed in Table 3.1.

Table 3.1 Sample size of deformed bars used in the analysis

Grade	Diameter of bar, mm								Total nos. of samples
	8	10	12	16	20	25	28	32	
Fe500	95	95	95	95	95	70	35	30	610
Fe500D	15	15	15	15	15	15	15	10	135

3.4 Sample preparation

For individual mill and brand, five numbers of samples were selected for each bar size. Among the five samples, for tensile testing three samples were used. The average value of three samples were used as average tensile properties (mass per meter run, yield strength, tensile strength, percentage elongation, UTS/YS ratio, and total elongation at maximum force). From the remaining two samples, at first bond value by area of projection method were calculated from one sample. Bond value testing is non-destructive test. Finally, bend test were conducted on one sample. Re-bend test sample

were prepared from remaining last sample among five and final re-bend test were conducted on the prepared sample. Bend and re-bend test are qualitative test performed on bend and re-bend test machine using proper mandrel and spacing of rollers.

For mechanical and physical testing of collected samples of different grades and brands, the following test method and product standard were followed:

1. Metallic Materials- Tensile Testing at Ambient Temperature (IS: 1608, 2005) / (ISO 6889: 1998)
2. Steel for the Reinforcement and Pre-stressing of Concrete- Test methods Part-1, (ISO 15630-1, 2019)
3. Metallic Materials- Tensile Testing, Part 1: Method of test at ambient temperature, (BS EN 10002-1, 2001)
4. Deformed Steel Bars and Wires for Concrete Reinforcement (NS:191, 2069)
5. High Strength Deformed Steel Bars and Wires for Concrete Reinforcement- Specification (IS:1786, 2008)

The following parameters were measured for preparation of collected samples for tensile testing:

3.4.1 Effective cross-sectional area of deformed bars

The effective cross-sectional area were determined from the length of bar and its weight. For bars whose pattern of deformation is such that by visual inspection, the cross-sectional area is substantially uniform along the length of bar, the effective cross-sectional area shall be the gross sectional area determined as follow, using reinforcement bar not less than 0.5 m in length. The density of steel shall be taken as 0.00785 kg/mm² of the cross-sectional area per meter run.

$$\text{Gross cross – sectional area in mm}^2 \text{ (So)} = \frac{W}{0.00785 * L} \quad \text{Equation 3.1}$$

Where,

W= mass in kg weighted to a precision of ±0.5 percent, and

L= length in m measured to a precision of ±0.5 percent

3.4.2 Marking original gauge length on deformed bars

With the help of calculated gross cross-sectional area (S_0) in Equation 3.1, the original gauge length (OGL) is determined by using Equation 3.2. The obtained value is rounded up. The original gauge length is marked on samples preparing for tensile test. Sometimes sub division of OGL is also marked to get precise results. The marking was done with the help of v-block, center punch and hammer. For Fe500D samples the sub multiple of calculated OGL were marked between two successive marks to calculate total elongation at maximum force from the longer part of broken samples after tensile test. The measurement of the final gauge length after fracture is made on longest broken part of the test piece and should be accurate to 0.5 mm.

$$\text{Original gauge length (OGL)} = 5.65\sqrt{S_0} \quad \text{Equation 3.2}$$

Where,

S_0 is gross cross-sectional area in mm^2

3.5 Mechanical testing of samples

To conduct the physical analysis and mechanical test of selected samples there needs some special machines and some measuring instruments. For this thesis work, NBSM physical testing laboratory was requested to provide testing facilities and use of their mechanical testing laboratory. NBSM granted the request to conduct test without affecting their regular testing work. NBSM mechanical testing laboratory was selected as there is facility for conducting all the physical and mechanical test of reinforcement bar as per specified in product standard for reinforcement bar. All the testing equipment are calibrated so the output results of the tests are reliable.

3.5.1 Tensile testing of samples

To conduct tensile testing of the samples two type of universal testing machines (UTM) were used. One UTM is of 600 kN capacity, Tinus Olsen, USA made, Figure 3.3 in which there is provision for selection of load range 60 kN, 300 kN and 600 kN. This helps for obtaining precise data for the individual sample. The 60 kN range is used for 8 mm and 10 mm size bars, where one division is 0.05 kN precision level. For 12 mm and 16 mm diameter 300 kN range were selected with one division equals to 0.25 kN and 600 kN with precision level of 0.5 kN used for 20 mm, 25 mm and 28 mm.



Figure 3.3 Tinus Olsen UTM machine 600 kN NBSM mechanical testing laboratory

Another UTM Machine is HEICO, shown in Figure 3.4, made in India which is of 1000 kN capacity with software based. During the thesis work it is tried to test most of samples in HEICO but due to the work load of regular sample of NBSM it was not possible to conclude all samples, so some samples are also tested in Tinus Olsen UTM machine. For 8 mm and 10 mm size the precise result can be obtained from 60 kN range than that of 1000 kN. Also for gripping there is problem in 1000 kN machine for smaller size and it arises slip problem. The yield load and maximum load were noted on observation sheet. With the help of gross cross-sectional using Equation 3.3 and Equation 3.4 yield strength and tensile strength were calculated. Percentage elongation and total elongation at maximum force was calculated using Equation 3.5 and Equation 3.6 respectively.

$$\text{Yield strength, MPa} = \frac{\text{Yield force, kN}}{\text{Gross cross-sectional area}} \times 1000 \quad \text{Equation 3.3}$$



Figure 3.4 Heico UTM machine 1000 kN at NBSM mechanical testing laboratory

$$\text{Tensile strength, MPa} = \frac{\text{Maximum load, kN}}{\text{Gross cross-sectional area}} \times 1000 \quad \text{Equation 3.4}$$

$$\text{Percentage elongation, \%} = \frac{\text{FGL} - \text{OGL}}{\text{OGL}} \times 100 \quad \text{Equation 3.5}$$

Where,

OGL is original gauge length

FGL is final gauge length

$$\text{Total elongation at maximum force, } A_{gt}, \% = A_g + \frac{R_m}{E} \times 100 \quad \text{Equation 3.6}$$

Where,

A_g = percentage non-proportional elongation at maximum force, %

R_m = stress corresponding to maximum force, kN

E = modulus of elasticity, N/mm^2

3.5.2 Bend test

NBSM mechanical testing laboratory has separate bend and Re-bend test machine, shown in Figure 3.5. It has two moving rollers to manage spacing for different sizes of reinforcement bar, one ram which operates by electric motor and hydraulic system. Different sizes of mandrels are available for test.

The bend test shall be performed in accordance with the requirements of (NS:333, 2050) and the mandrel diameter shall be as specified in Table 3.2. The specimen shall be considered to have passed the test if there is no transverse crack in the bent portion.

Table 3.2 Mandrel diameter for bend test

Nominal Size, mm	Mandrel Diameters for Different Grades		
	Fe 415 & 415D	Fe 500 & 500D	Fe 550, 550D & 600
Up to and including 22	3Ø	4Ø	5Ø
Over 22	4Ø	5Ø	6Ø
Where Ø is the nominal size in mm of test piece.			
$l = D + 3a$, where l is distance between supports, D is diameter of mandrel and a is diameter of test piece.			

(Source: NS:191, Table 3)



Figure 3.5 Bend and re-bend test machine at NBSM

3.5.3 Re-bend test

The test piece shall be bent to an included angle of 135° using a mandrel of appropriate diameter using Table 3.3. The bent piece shall be aged by keeping in boiling water (100°C) for 30 minutes and then allowed to cool. The piece shall then be bent back to have an included angle of $157\frac{1}{2}^{\circ}$. The specimen shall be considered to have passed the test if there is no fracture in the bent portion. The procedure for re-bend test is shown in Figure 3.6.

Table 3.3 Diameter of mandrel for re-bend test

Nominal Size, mm	Mandrel Diameters for Different Grades	
	Fe 415 & 415D and Fe 500 & 500D	Fe 550, 550D & 600
Up to and including 10	$5\varnothing$	$7\varnothing$
Over 10	$7\varnothing$	$8\varnothing$

Where \varnothing is the nominal size in mm of test piece.

$l = D + 3a$, where l is distance between supports, D is diameter of mandrel and a , is diameter of test piece.

(Source: NS:191, 8.4.1)

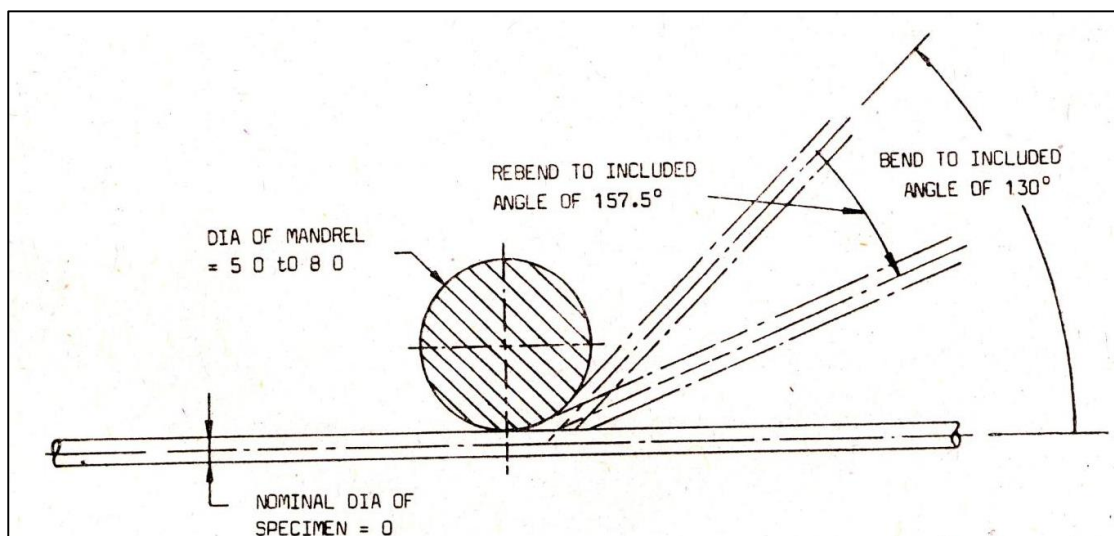


Figure 3.6 Re-bend test procedure (NS:191, Fig.2)

3.5.4 Bond test

For high strength deformed bars the mean area of ribs (in mm²) above the core of the bar, projected on a plane paper normal to the axis of the bar is calculated using Equation 3.7.

$$A_r = \frac{A_{tr} \times \sin \theta}{S_{tr}} \quad \text{Equation 3.7}$$

Where,

A_{tr} = area of longitudinal section of a transverse rib on its own axis;

θ = inclination of transverse rib to the bar axis (average value of two ribs from each row of transverse ribs shall be taken);

S_{tr} = spacing of transverse ribs in mm

The value of A_{tr} is calculated using Equation 3.8.

$$A_{tr} = \frac{2}{3} \times l_{tr} \times d_{tr} \quad \text{Equation 3.8}$$

The different terms related to calculation of A_{tr} is shown in Figure 3.7.

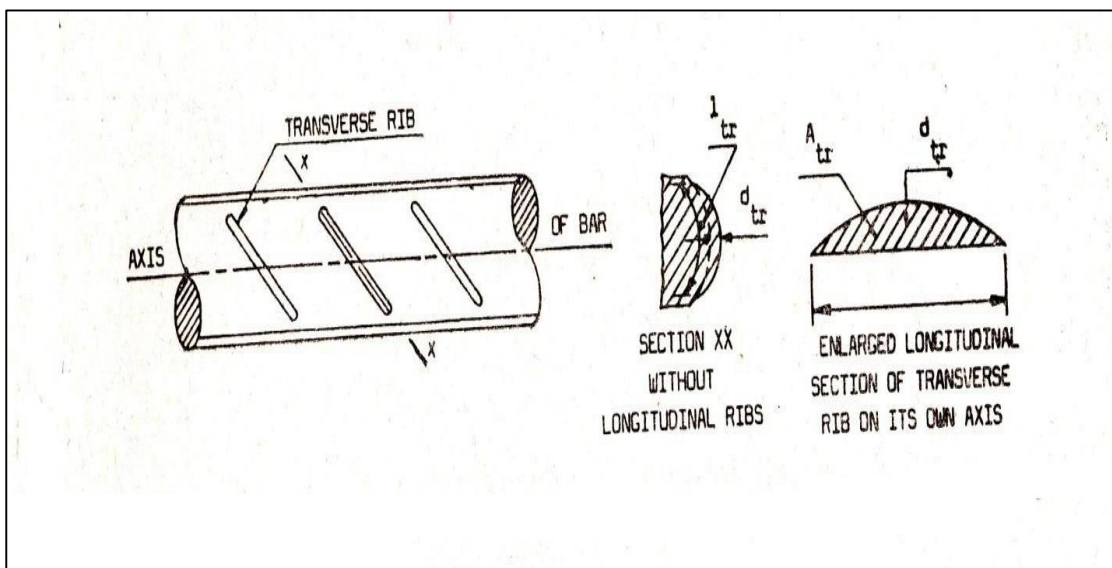


Figure 3.7 Determination of longitudinal sectional area A_{tr} of a transverse rib

(Source: NS:191, Fig.1)

Note: A_{tr} , d_{tr} , and l_{tr} represent longitudinal section area, height and length respectively of transverse rib.

The calculated bond value using Equation 3.7 shall not be less than the values shown in Table 3.4.

Table 3.4 Minimum bond value requirement

Requirement	Nominal Size, mm	Bond Value, Min. mm
0.12 ϕ for $\phi \leq 10$ mm	8	0.96
	10	1.2
0.15 ϕ for 10 mm < $\phi \leq 16$ mm	12	1.8
	16	1.8
0.17 ϕ for $\phi > 16$ mm	20	3.4
	25	4.25
	28	4.76
	32	5.44
Where ϕ is the nominal diameter of bar/wire in mm		

(Source: NS:191, Clause 4.2)

3.6 Statistical Analysis

The collected samples were tested at NBSM mechanical testing laboratory. The data obtained from test results are statistically analyzed to evaluate the variability in the properties of steel reinforcement. Mass per meter run, yield strength, tensile strength, percentage elongation, UTS/YS ratio, total elongation at maximum force and bond value are assessed in terms of the requirements as set forth by NS. Different bar sizes are compared and a mill-by-mill comparison is made to evaluate the variability between mills. The statistical analyses are conducted using Microsoft Excel. For the tested mechanical properties, the following parameters are evaluated for each bar size, and grade at confidence level at 95%: mean, standard deviation, coefficient of variation, minimum, maximum, skewness, and kurtosis. The skewness is the measure of symmetry. Negative value indicates data is skewed to the left and positive values indicate data that is skewed to the right. The kurtosis is a measure of whether the data is peaked or flat relative to normal distribution. An increased kurtosis indicates an increase peak near the mean of the data.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

Deformed steel bars conforming to the Nepal Standards (NS:191, 2069) has been commercially available and widely used over the past years. TMT bar of grade Fe500 is mostly manufactured by the steel industries. However, TMT bar of grade Fe500D is improved form of Fe500 grade. Fe500D grade of TMT bar has different chemical composition than Fe500 TMT bars. Fe500D grade TMT bars have lower Carbon, Sulphur, and Phosphorous percent than Fe 500 grade. Although, the minimum yield stress value is same as Fe500 grade, it has high ductility, higher value of ultimate tensile stress and one additional parameter total elongation at maximum force is added for this grade. In order to evaluate the mechanical properties of this steel, statistical studies were carried out based on extensive measured data. The NS:191 specified the chemical composition and manufacturing method of raw material also called billets. Billets shall be manufactured by the open-hearth, electric, duplex, basic oxygen or a composition of these processes. The ladle analysis of steel shall be as shown in Table 4.1. The bars shall be manufactured from properly identified heats of mould cast.

Table 4.1 Chemical composition of steel

Constituents	Percent, Max.	
	Fe500	Fe500D
Carbon	0.30	0.25
Sulphur	0.055	0.040
Phosphorus	0.055	0.040
Sulphur & Phosphorus	0.105	0.075

(Source: NS:191, Clause 3.3)

For guaranteed weldability, the carbon equivalent, CE using Equation 4.1 shall not be more than 0.53 percent.

$$CE = C + \frac{Mn}{6} + \frac{(Cr+Mo+V)}{5} + \frac{(Ni+Cu)}{15} \quad \text{Equation 4.1}$$

When micro alloys/low alloys are not used, carbon equivalent using Equation 4.2 shall not be more than 0.42 percent.

$$CE = C + \frac{Mn}{6} \quad \text{Equation 4.2}$$

For product analysis, the permissible variation from the limits specified in Table 4.1 shall be as mentioned in Table 4.2.

Table 4.2 Permissible variation of chemical composition for product analysis

Constituent	Variation over specified max. limit, Percent, Max.
Carbon	0.02
Sulphur	0.005
Phosphorus	0.005
Sulphur & Phosphorous	0.010

For the two grades of deformed steel bars, the distribution of yield strength, tensile strength, percentage elongation, UTS/YS ratio, bend test, re-bend test and bond value were determined based on the data generated from tensile tests on the collected samples. Bend and Re-bend tests are qualitative test conducted based on test method. Bond test is conducted by area of projection method mentioned in NS: 191.

Linear regression analyses were carried out on different sets of data to investigate the correlation between the properties.

In this report a statistical analysis is conducted to evaluate the physical and mechanical properties of reinforcing steel bars and to compare these properties with minimum NS standard. Additionally, inter-relation between applied load, diameters of bars, and other mechanical properties were established from plotted graph and some equations are established with the help of graphs.

4.1 Comparing Data with Minimum NS Standard

In comparing tested results data with the minimum standards set forth by NS, the following observations are made:

4.1.1 Yield strength

A value of yield strength was tested for 435 numbers of individual samples for this study. All the tested samples comply with the minimum NS standard requirement for their respective grade. The minimum yield strength value is 500 MPa for both Fe500 and Fe500D TMT bar specified in (NS:191, 2069).

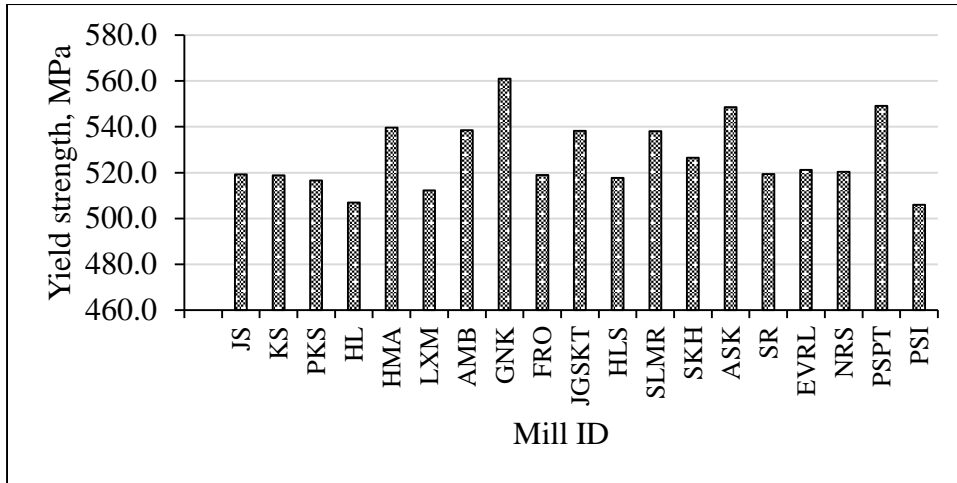


Figure 4.1 Minimum yield stress value for each mill Fe500

The minimum yield stress value for each mill is presented in Figure 4.1. From the figure, it is evident that all the tested samples comply with minimum yield strength value specified in NS-191. Although it is observed that there is large range of variation. The reason behind these variation may be different rolling practice among the hot rolling mills, billets from different batch/heats, water pressure, equalizing temperature and variation in chemical composition of billet materials. It is evident that most of the minimum yield strength value were observed near 520 MPa. The minimum yield strength value according to size is presented in Figure 4.2 below.

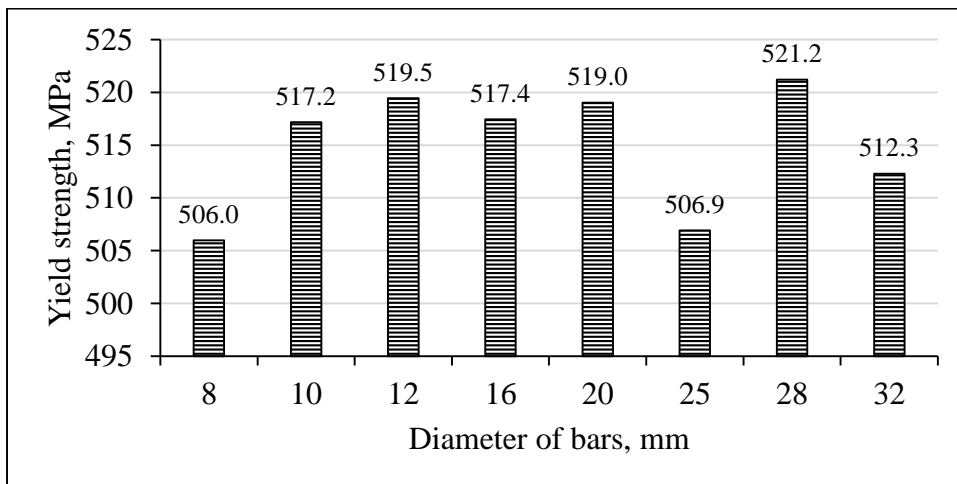


Figure 4.2 Minimum yield strength for bar size Fe500

From Figure 4.2 it is observed that the minimum yield stress value for each bar size are well above the set standard yield stress value. For bar size 8 mm and 25 mm the lowest yield strength value were observed. Except 32 mm bar size others have minimum yield

stress value were observed above 515 MPa. The process control for lower size is difficult to attain the set standard.

Table 4.3 Minimum yield stress value for Fe500D bar size

Minimum Value for Fe500D	Diameter of Bars, mm							
	8	10	12	16	20	25	28	32
Yield Strength, MPa	539.0	512.5	547.1	556.0	520.9	556.6	530.9	551.0
NS: 191	Min. 500 MPa for all bar size							

The minimum yield strength value for Fe500D grade TMT bars are presented in Table 4.3. It is evident from the table all the tested samples comply for minimum yield stress value specified in NS-191. From above table it is evident that for bar size 10 mm the yield strength value were observed 512.5 MPa. All the other size except 10 mm have yield stress value above 520 MPa. It is also evident that the minimum value of yield stress for Fe500D bar size has higher than those for Fe500 grade presented in Figure 4.2. The reason behind this may be improved chemical composition of billet materials.

4.1.2 Tensile strength

Total 145 sets of samples were tested at NBSM mechanical testing laboratory. Each set represents the mean value of three samples. The below Figure 4.3 represents the minimum tensile strength value obtained for each mill.

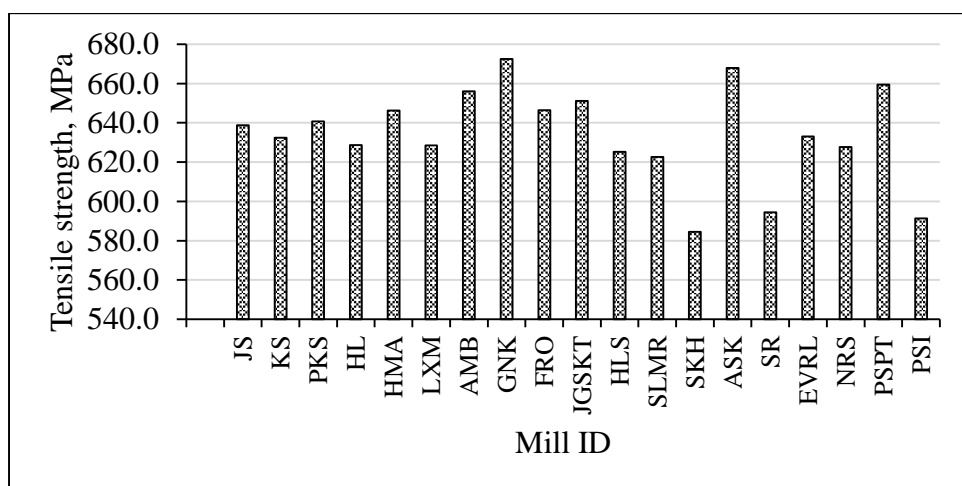


Figure 4.3 Minimum tensile strength value for each mill Fe500

The minimum value for Fe500 TMT bar specified in NS-191 is 8% more than actual yield stress but not less than 545.0 MPa. All the tested samples comply with the

minimum value specified in product standard. From Figure 4.3 it is evident that the minimum values for mill SKH, SR and PSI have only below 600 MPa. Most of the minimum tensile strength values were found above 620 MPa. The minimum tensile strength value of tested samples are presented in Figure 4.4 according to size of bars.

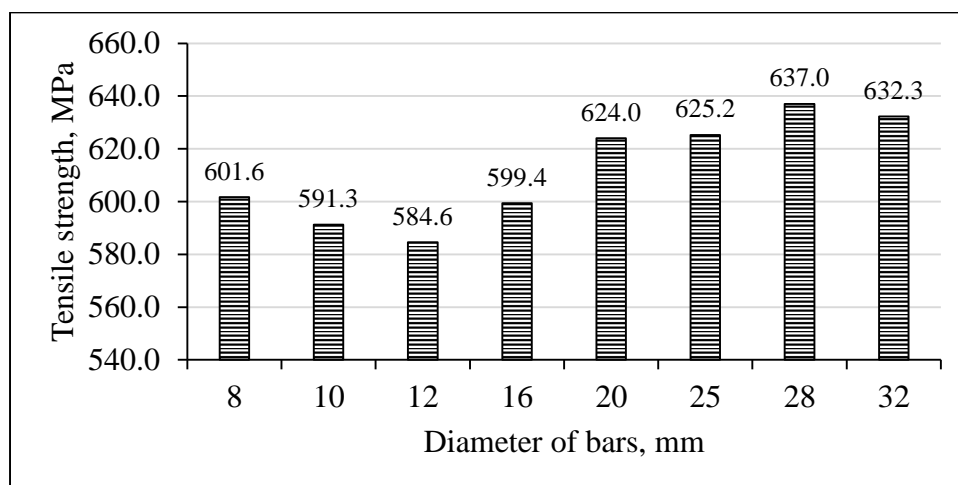


Figure 4.4 Minimum tensile strength for bar size Fe500

From Figure 4.4 it is observed that the lowest tensile strength value were obtained for 12 mm bar size and highest minimum yield strength for 28 mm bar size. It is also observed from above figure that bar size above 16 mm size have minimum yield strength value above 620 MPa. Tensile strength is also directly related to billet chemical composition, rolling practice, water pressure, equalizing temperature of rolling mills. It also depends on cooling time and methods of cooling at cooling stand during the production process.

Table 4.4 Minimum tensile strength value Fe500D bar size

Minimum Value for Fe500D	Diameter of Bars, mm							
	8	10	12	16	20	25	28	32
Tensile Strength, MPa	623.9	616.5	661.0	670.9	644.8	671.2	659.1	668.1
NS: 191	Min. 10% more than actual Y.S. but not less than 565.0 MPa							

Minimum tensile strength value for Fe500D grade TMT bars are presented in Table 4.4. For Fe500D grade TMT bars the minimum value specified in product standard is 10% more than actual yield stress but not less than 565.0 MPa. All the tested samples comply the minimum tensile strength value specified in NS-191. From the above table it is evident that the minimum tensile strength value was obtained for 10 mm bar size.

As mentioned for yield stress minimum value of Fe500D was higher than Fe500, same trend for tensile strength is evident.

4.1.3 Percentage elongation

The elongation measured over the gauge length at fracture as a percentage of the original gauge length is used to represent the ductility of the steel. Ductility is also a function of the strength of steels. The minimum value of percentage elongation obtained for each rolling mill is presented in Table 4.5 below.

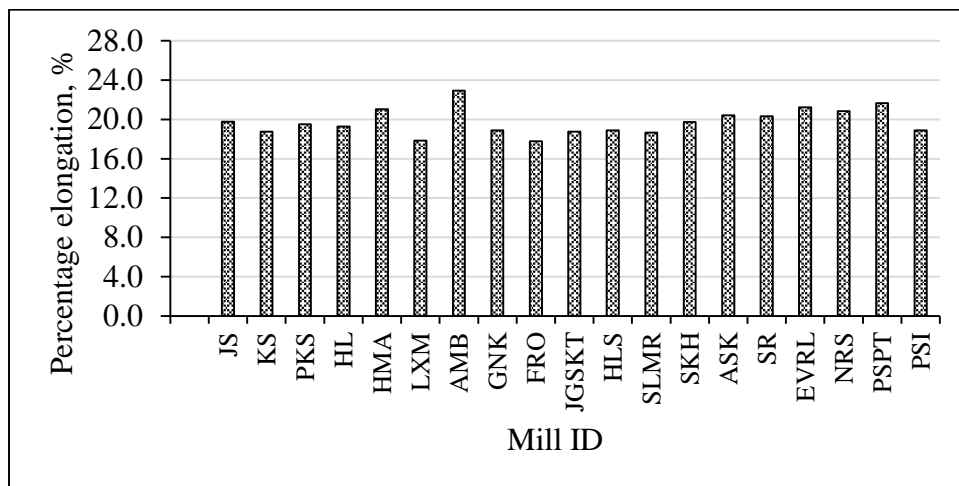


Figure 4.5 Minimum value of percentage elongation for each mill Fe500

The minimum value of percentage elongation for Fe500 TMT bars specified in product standard is 12%. All the tested samples comply with the minimum value specified in product standard. From the test results, it was observed that the test results are above 16% for all rolling mills. The minimum value of percentage elongation for mill AMB were found higher among the mills. The minimum value of percentage elongation for most of the rolling mills were found between 16% and 20%.

The minimum value for percentage elongation of Fe500 grade TMT bars according to bar size is shown in Figure 4.5. From the bar chart it is evident that all bars size comply the minimum value specified in product standard, 12%. From figure it is observed that the bar size 12 mm and 28 mm have minimum percentage elongation value between 16% and 17%. The higher diameter of bars 12 mm, 16 mm, 20 mm, 25 mm and 28 mm have minimum value of percentage elongation between 18% and 19%. For the bar size 8 mm and 10 mm size the value of minimum percentage elongation were observed above 20%. In general, higher-strength high-carbon steels are less ductile than lower-strength low-carbon steels.

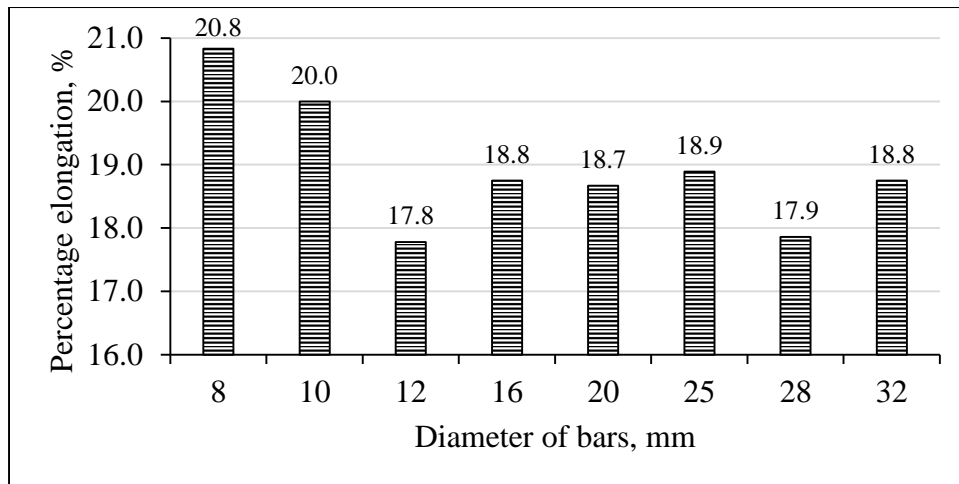


Figure 4.6 Minimum percentage elongation Fe500 bar size

Table 4.5 Minimum value of percentage elongation Fe500D bar size

Minimum Value for Fe500D	Diameter of Bars, mm							
	8	10	12	16	20	25	28	32
Percentage Elongation, %	21.7	22.7	21.1	19.6	20.3	19.4	19.8	21.3
NS: 191	Min. 16.0%							

The minimum value of percentage elongation of Fe500D grade TMT bars tested samples are presented in Table 4.5. The minimum value specified in NS-191 for Fe500D grade is 16%. All the tested sample comply with minimum requirement specified in product standard. From the table it is evident that for bar size 16 mm, 25 mm and 28 mm size the minimum value of percentage elongation are below 20%. In comparison to Fe500 grade the minimum percentage elongation values for Fe500D grade are higher. But one thing found common that is the minimum values for bar size 8 mm and 10 mm size have higher minimum percentage elongation value for Fe500 and Fe500D grade. The reason behind this is superior chemical composition than that of Fe500 grade TMT bars raw material.

4.1.4 Bond value

Total 122 numbers of Fe500 TMT bars and 23 numbers of Fe500D TMT bars were tested by area of projection method for bond value calculation.

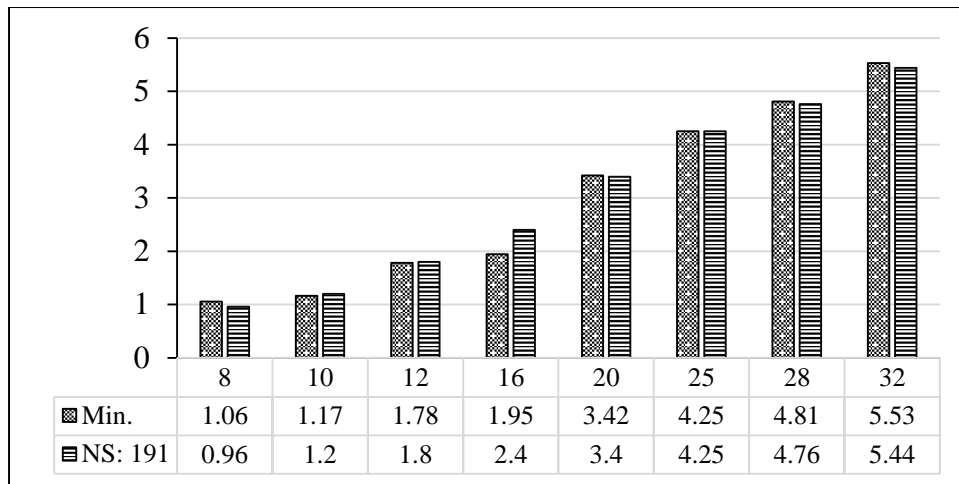


Figure 4.7 Minimum bond value for Fe500 bar size

The minimum value of bond calculated by area of projection method for Fe500 grade TMT bars are presented in Figure 4.4. Among the tested samples 3 (2.45%) did not comply with the minimum NS standards for their respective bar size, and grade. The sample coded with AMB_10 mm, SR_12 mm and PKS_16 mm were not comply with minimum requirement. Although these samples bond value were very close to minimum value set by NS. Sample AMB are short by 0.03, SR by 0.02 and PKS by 0.45 with value specified in product standard for respective bar size.

4.1.5 Mass per meter run

Mass per meter run is calculated for 435 numbers of samples from grade Fe500 and Fe500D. All the tested samples comply with minimum value specified in product standard for their respective bar size, and grade. Since all the tested samples are treated as individual, the given lower tolerances for respective sizes were taken in consideration. All the tested samples were found within the tolerance limit specified in product standard.

4.1.6 Total elongation at maximum force

This mechanical properties is added parameters for Fe500D TMT bars to check their ductility. Total 69 numbers of samples of Fe500D grade were tested for this mechanical properties. All the tested samples were comply with minimum value specified in product standard. The minimum value specified for Fe500D grade is 5.0%.

4.1.7 Bend and re-bend test status

Bend and re-bend test are qualitative test. All the tested samples of both grade Fe500 and Fe500D comply with the NS requirements. Total 145 samples of different size and grades are tested. No transverse crack were found in the bent portion of the sample tested for bend test. There is no fracture were found in the bent portion for samples tested for re-bend test. The percentage elongation value is also more than minimum NS requirements satisfy the qualitative test results.

4.2 Data Trends: Bar Sizes and Grades

There are basically two grades of reinforcing steel being tested in this thesis work, namely Fe500 and Fe500D TMT bars. In this thesis work, it is tried to include all the available sizes of reinforcement bar. However, most of the industries have granted the license for producing 8 mm to 32 mm size, they only produce common size of reinforcement bar and the bigger size is produced as per market demand only.

4.2.1 Yield strength

There is significant trend observed in the data for yield strength of Fe500 TMT bars. Here, the average yield strength first decreases from 573.9 MPa for 8 mm bars to 544.8 MPa for 16 mm bars and then increases steadily with bar sizes. The lowest average value of yield strength were found for 32 mm bars. Overall, the average yield strength is 554.4 MPa for all Fe 500 TMT bars. Figure 4.8 below shows the data trends for 8 mm to 32 mm bar size of grade Fe500 TMT bars.

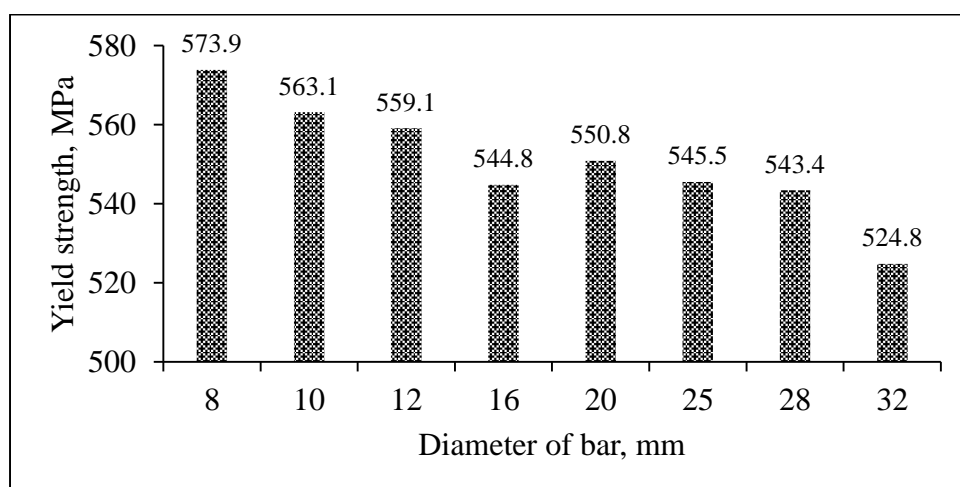


Figure 4.8 Data trends for average yield strength Fe500 TMT bars

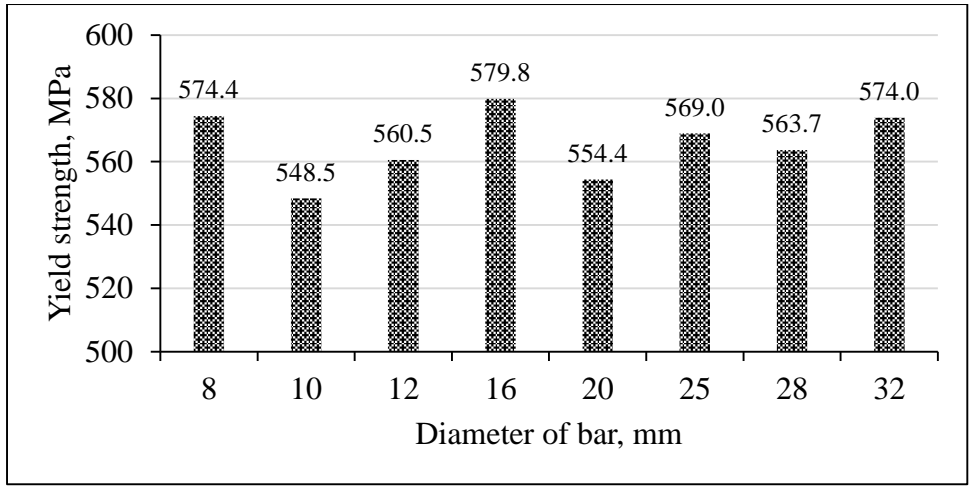


Figure 4.9 Data trends for average yield strength Fe500D TMT bars

Figure 4.9 shows the data trends for Fe500D TMT bars. For bar of grade Fe500D, the average yield strength were 565.2 MPa. From bar chart it is evident that bar size of 16 mm size has the highest average yield strength value 579.8 MPa and 10 mm bar size has lowest average yield strength value 548.5 MPa.

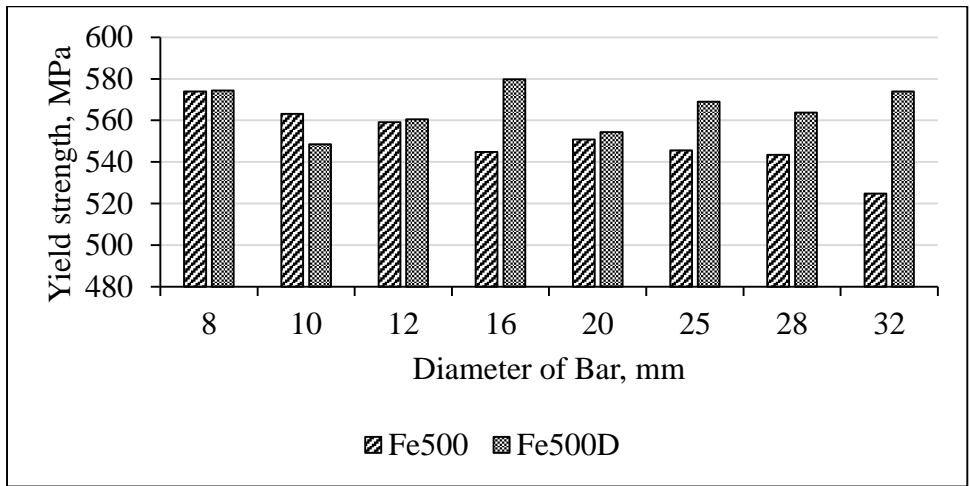


Figure 4.10 Average yield strength data trend for Fe500 and Fe500D grade

Figure 4.10 shows the comparison of average yield strength value for grade Fe500 and Fe500D. From figure it is evident that the average yield stress value of all sizes of Fe500D is upper than Fe500 except 10 mm bar size.

The variability in mechanical properties of deformed bars have very significant influence on the safety of structure. The variability can be minimized if desired level of quality control in each phase of production is strictly adhered to. Statistical analysis of the test results of tensile properties of 366 samples were carried out for TMT bars of grade Fe500 and the results are as shown in Table 4.6.

Table 4.6 Statistical summary of tensile test results Fe500 TMT bars

Tensile parameters Fe500 TMT bars				
Descriptive Statistics	Yield Strength, MPa	Tensile Strength, MPa	Percentage Elongation, %	UTS/YS ratio
Mean	554.4	663.4	22.0	1.20
Coefficient of Variation	4.7	4.2	8.2	2.50
Standard Deviation	25.8	28.2	1.8	0.03

The study conducted by Mirza and MacGregor (1979) was based on a sample of 3,947 bars taken from 13 sources. In their analysis they found that the coefficient of variation (COV) of yield strength for reinforcing bars taken from various sources ranged from 5 to 8 percent for individual bar sizes. Their data consisted of Grade 40 and Grade 60 steel. Similarly, Allen (1972), whose study was based on two data samples, one consisting of 132 bars and the other consisting of 102 bars obtained from five heats, found the COV for yield strength to be 7 to 8 percent for grade 40 bars. The coefficient of variation for yield strength and tensile strength were found 4.7 and 4.2 percent respectively. Only for percentage elongation parameter the COV value were calculated 8.2 percent. Higher COV value indicates larger range of variation for percentage elongation.

Table 4.7 Statistical summary of tensile test results Fe500D TMT bars

Tensile Parameters, Fe500D TMT bars					
Descriptive Statistics	Yield Strength, MPa	Tensile Strength, MPa	Percentage Elongation, %	UTS/YS ratio	Total Elongation at Max. Force, %
Mean	565.2	678.1	22.0	1.20	8.27
Coefficient of Variation	4.4	3.9	6.8	2.06	21.71
Standard Deviation	24.9	26.5	1.5	0.02	1.80

Statistical analysis of the test results of tensile properties of 69 samples were carried out for TMT bars of grade Fe500D and the results are as shown in Table 4.7. The COV for yield strength and tensile strength were found 4.4 and 3.9 percent respectively. For percentage elongation parameter the COV value were calculated 6.8 percent. The coefficient of variation of total elongation at maximum force is on the higher side, it should be within 10 percent.

4.2.2 Tensile strength

The data trend of average tensile strength for Fe500 grade TMT bars are shown in Figure 4.11. From bar chart it is evident that the average value of tensile strength for all the bar size are above 645.6 MPa.

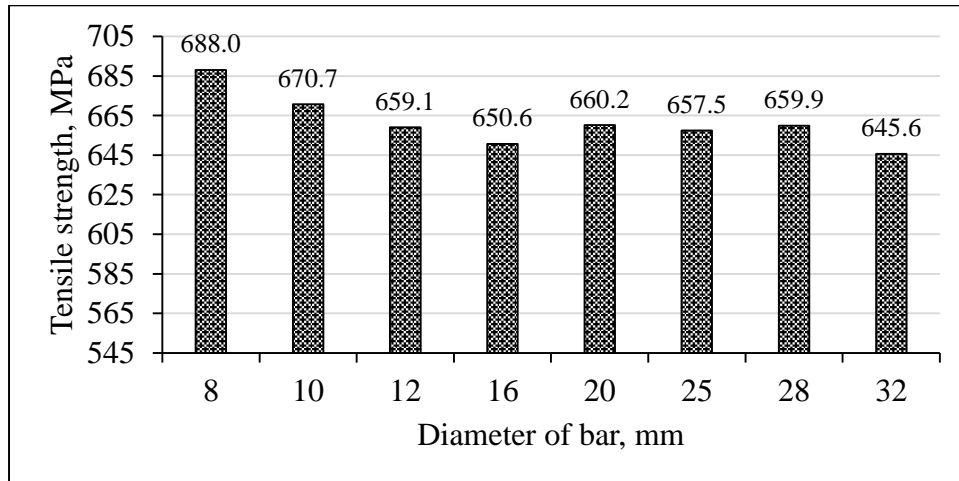


Figure 4.11 Data trends for average tensile strength Fe500 TMT bars

Unlike yield strength, the tensile strength of Fe500 TMT bars generally decreases with an increase in bar diameter 688.0 MPa to 650.6 MPa, from 8 mm to 16 mm. From 20 mm to 28 mm bars show the average tensile strength value almost constant. For 32 mm bar size the lowest average tensile strength were found as shown in Figure 4.11. The mean value of tensile strength for Fe500 grade was found 663.4 MPa with minimum value 584.6 MPa and maximum value 730.3 MPa.

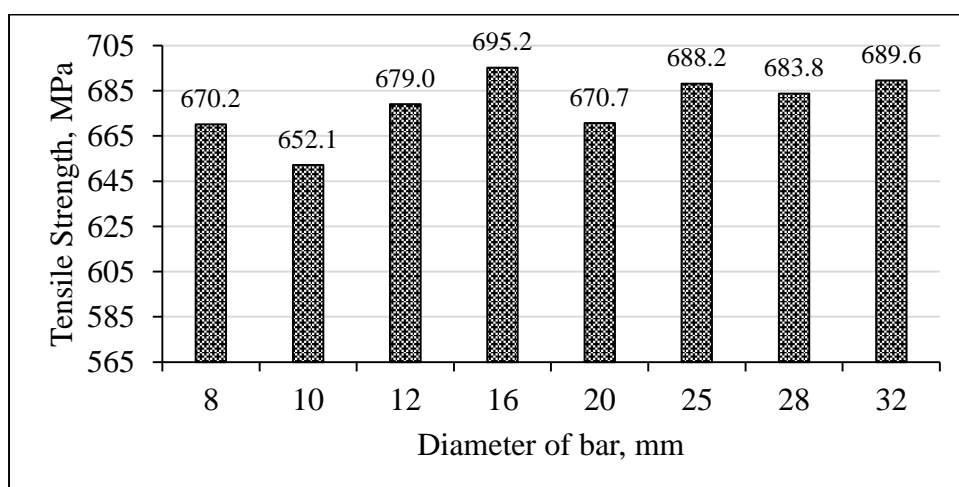


Figure 4.12 Data trends for average tensile strength Fe500D TMT bars

The data trends for average tensile strength for Fe500D samples are shown in Figure 4.12. Range in tensile strength for Fe500D samples are 616.5 MPa to 716.9 MPa. There is more variation in tensile strength found for Fe500D grade than Fe500 TMT bars samples. The Coefficient of variation for both grade was found below 5 percent.

4.2.3 Percentage elongation

Percentage elongation is the measure of ductility were found to be higher than the requirements of product standard. The term ductility refers to the ability of a member to undergo large deformation under tension without rupture as failure is occurring. Ductile members could therefore bend and deform excessively but they remain intact. This value also directly related with chemical composition of billet. It is also related with tensile strength, higher the tensile strength, lower the value of percentage elongation.

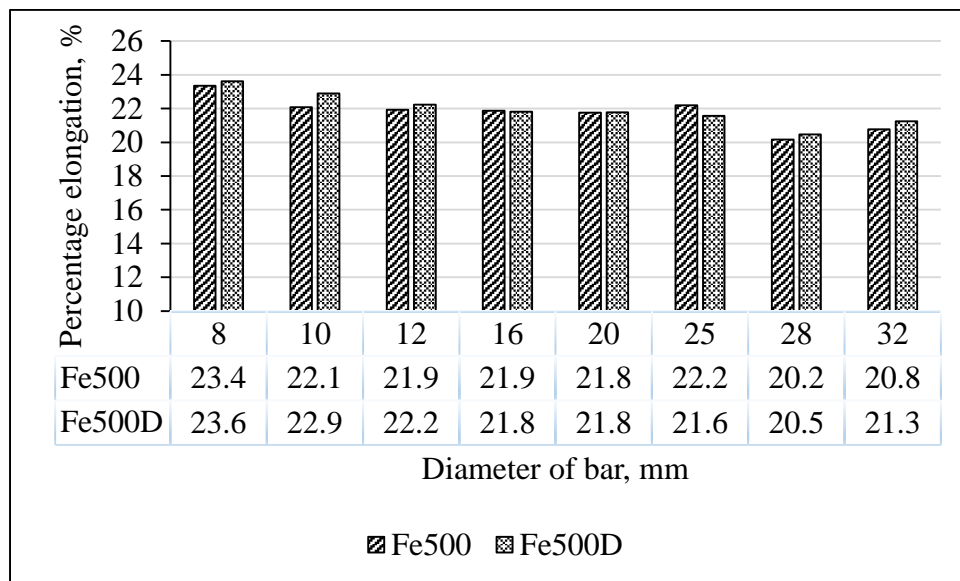


Figure 4.13 Data trend for avg. percentage elongation Fe500 and Fe500D TMT bars
 The average percentage elongation for Fe500 TMT bars were found from the tested sample is 22.0%. The maximum value of percentage elongation of tested samples was found 26.7% and minimum value 17.8%. Figure 4.13 show the data trend for both grade Fe500 and Fe500D TMT bar. From Figure 4.13 it is evident that the percentage elongation value for lower diameter have more than that for higher diameter. For Fe500D grade TMT bars, the mean value of percentage elongation found from the tested samples was 22.0%, with maximum value 25.0% and minimum Value 19.4%.

4.2.4 UTS/YS ratio

The average value of UTS/YS ratio for all the tested samples of both grade Fe500 and Fe500D TMT bars were found 1.2. There is a significant trend observed in Figure 4.14 for UTS/YS ratio of grade Fe500 bars. The average UTS/YS ratio first decreases from 1.20 for 8 mm bars to 1.18 for 12 mm and then increases steadily with bar size to a maximum average UTS/YS ratio 1.23 for 32 mm bars.

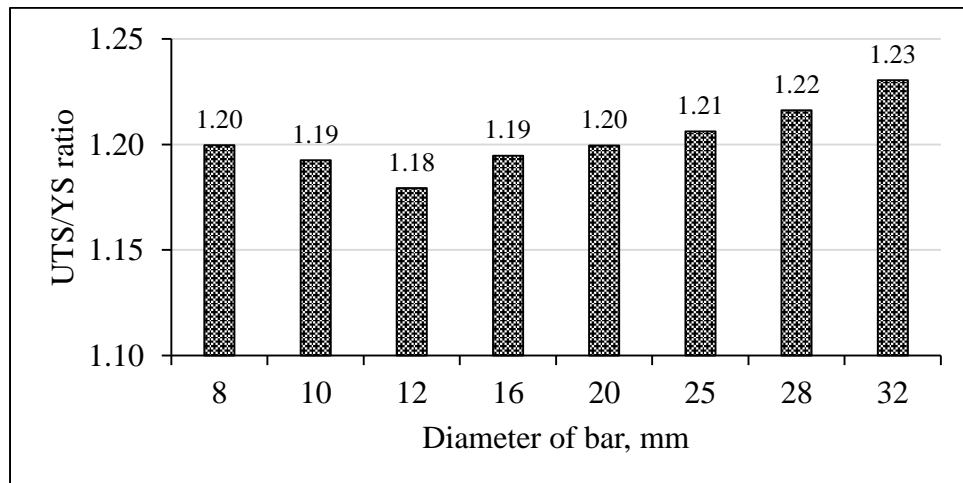


Figure 4.14 Data trends for average UTS/YS ratio Fe500 TMT bars

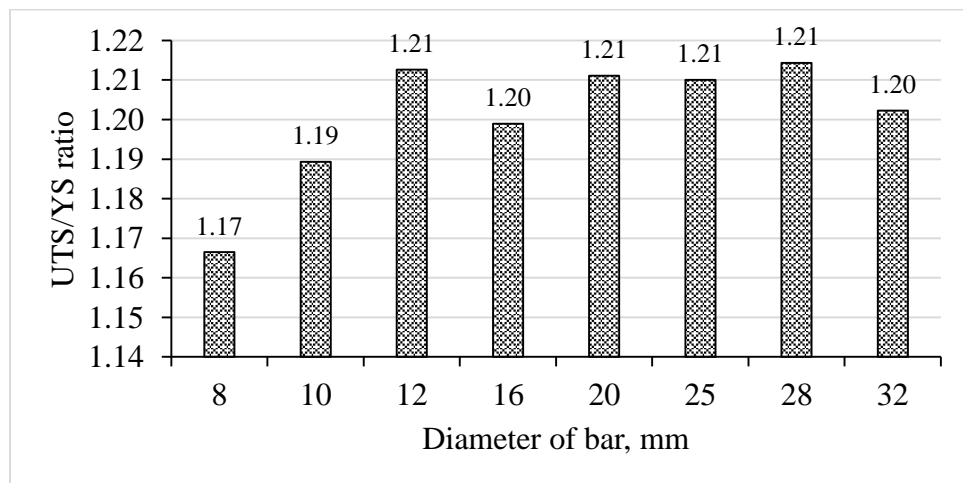


Figure 4.15 Average UTS/YS ratio for Fe500D TMT bars

The Figure 4.15 show the data trend of average value of UTS/YS ratio of Fe500 TMT bars. For Fe 500D grade not such trend is observed. The minimum average UTS/YS ratio was observed for 8 mm bars. Except 10 mm bars, all other sizes have average UTS/YS ratio above 1.20. The maximum average UTS/YS ratio values are observed for 1.24 for 28 mm bars. Since the tested values of UTS/YS ratio for both grades are above 1.15 which is good sign for material properties.

4.2.5 Bond value

The bond value of all the tested samples are conducted by area of projection method. The average bond value for individual size and grade are shown in Tables 4.8 and 4.9 below. High range of variation for both grades and sizes of bars were witnessed. The value of COV for Fe500 grade is in decreasing order. The values of COV for bond strength between 27.47 to 15.46, and exhibited a general decrease in COV with an increase in bar size. Similar trend of COV value for Fe500D grade was observed, 26.86 to 5.68 percent.

Table 4.8 Data trends for bond value Fe500 TMT bars

Fe500 TMT bar, Bond value, mm								
	Bar Size, mm							
	8	10	12	16	20	25	28	32
Average	1.69	1.93	2.65	3.65	4.59	5.23	5.97	6.43
Max.	2.89	2.59	3.67	5.48	6.49	7.72	7.44	7.99
Min.	1.06	1.17	1.78	1.95	3.42	4.25	4.81	5.53
NS: 191	0.96	1.20	1.80	2.40	3.40	4.25	4.76	5.44
Std. Dev.	0.47	0.38	0.63	0.98	0.87	0.94	0.94	0.99
COV	27.47	19.56	23.97	26.88	19.01	18.04	15.82	15.46

From Table 4.8 it is observed that the range of variation of calculated bond value is high. The reason behind higher value of COV in the case of bond value results are the range of variation. The ratio of maximum value to minimum value is 2.74, 2.22, 2.06, 2.82, 1.90, 1.81, 1.55 and 1.45 percent from 8 mm bar size to 32 mm bar size respectively. So higher the range of test data between minimum and maximum test results are responsible for higher COV in the case of Fe500 grade TMT bars.

Table 4.9 Data trends for bond value Fe500D TMT bars

Fe500D TMT bar, Bond value, mm								
	Bar Size, mm							
	8	10	12	16	20	25	28	32
Average	1.30	2.16	3.47	3.57	4.95	5.52	5.77	6.87
Max.	1.70	2.35	4.49	4.37	5.11	6.00	6.39	7.16
Min.	1.06	1.78	2.60	2.80	4.62	4.78	5.15	6.58
NS: 191	0.96	1.2	1.8	2.4	3.4	4.25	4.76	5.44
Std. Dev.	0.35	0.33	0.95	0.79	0.28	0.65	0.62	0.42
COV	26.86	15.1	27.36	22.03	5.68	11.81	10.77	6.05

From Table 4.9 it is observed that the range of variation of calculated bond value is high for 8 mm, 12 mm and 16 mm bar size. The reason behind higher value of COV in the case of bond value results are the range of test results. The ratio of maximum value to minimum value is 1.61, 1.32, 1.72, 1.56, 1.11, 1.25, 1.24 and 1.09 percent from 8 mm bar size to 32 mm bar size respectively. So higher the range of test data between minimum and maximum test results are responsible for higher COV in the case of Fe500D grade TMT bars for 8 mm, 12 mm and 16 mm bar size.

4.2.6 Mass per meter run

The average mass per meter run for all size and grade are shown in Tables 4.10 and 4.11 below.

Table 4.10 Data trends for mass per meter run Fe500 TMT bars

Mass per meter run, kg/m, Fe500								
Descriptive Statistics	Nominal Diameter, mm							
	8	10	12	16	20	25	28	32
Mean	0.398	0.604	0.879	1.553	2.451	3.813	4.755	6.217
Coefficient of Variation	2.518	1.725	0.996	0.887	1.321	1.181	1.293	0.648
Standard Deviation	0.010	0.010	0.009	0.014	0.032	0.045	0.061	0.040
Minimum	0.379	0.592	0.864	1.519	2.409	3.749	4.682	6.177
Maximum	0.411	0.627	0.894	1.577	2.526	3.883	4.840	6.286

Table 4.11 Data trends for mass per meter run Fe500D TMT bars

Mass per meter run, kg/m, Fe500D								
Descriptive Statistics	Nominal Diameter, mm							
	8	10	12	16	20	25	28	32
Mean	0.397	0.608	0.875	1.554	2.427	3.793	4.790	6.242
Coefficient of Variation	3.366	2.305	1.441	0.412	0.742	1.029	0.877	0.273
Standard Deviation	0.013	0.014	0.013	0.006	0.018	0.039	0.042	0.017
Minimum	0.381	0.598	0.860	1.550	2.409	3.754	4.760	6.230
Maximum	0.406	0.624	0.882	1.562	2.445	3.832	4.820	6.254

Mass per meter run determines the diameter and roundness of bar which is important for selecting the bar diameter in design. In this research work, each bar size was considered as individual sample so the tolerance for nominal mass was used. The values of COV for Fe500 TMT bars were found from 0.648 to 2.518 percent. The values of COV for Fe500D TMT bars were found from 0.273 to 3.366 percent. The COV value

is less than 5 percent for both grade Fe500 and Fe500D. The reason behind lower COV value is less variation in data obtained from tested samples. The values of mass per meter run for both grade are close to average value.

4.2.7 Total elongation at maximum force

Ductility of reinforcing steel may be regarded as its ability to undergo plastic deformation. The test most commonly used to achieve a quantitative value for ductility is tensile test. The product standard and test method for Fe500D grade requires the measurement of both elongation at maximum load (A_{gt}) and the ratio between the ultimate tensile strength of the steel (R_m) and its yield strength (R_e). A_{gt} , which is the percentage total elongation at maximum force, is that measure of elongation which excludes that considerable and highly localized extension of steel under test in area of plastic instability adjacent to the point of fracture. A_{gt} is therefore considered as a more useful measure of ductility for use in design applications for concrete structures. Figure 4.16 shows the data trends for total elongation at maximum force.

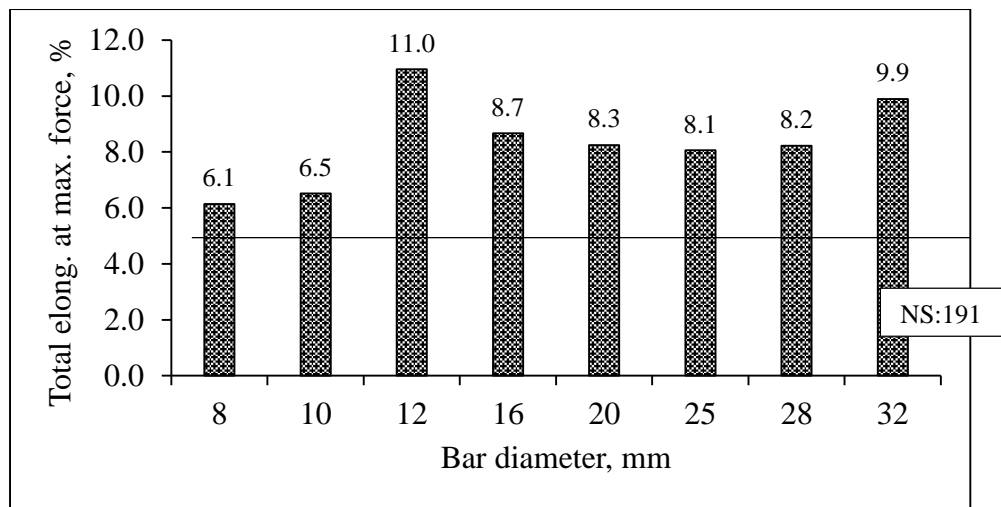


Figure 4.16 Data trends for total elongation at max. Force Fe500D TMT bars

This parameter is specified for Fe500D grade in NS:191. All the tested samples have values above 6 percent. For 12 mm bar size the value obtained from the test result is 11.0% which is more than double specified in standards. This grade of bar exhibited COVs from 21.96 to 8.59 percent. The higher COV values are obtained from sample size which has large range of variation between minimum and maximum values of data obtained from test results.

4.3 Data Trends: Mills

For the TMT bar manufacturing process, rolling mills with automatic cooling bed is essential. Proper control at finishing and equalizing temperature, temperature of circulating water, mill speed, and water pressure are essential to ensure the quality of finished products. Good quality raw material (billet) having desired chemical composition and no casting defects, skilled manpower, and process control are prerequisites for producing TMT bars of desired quality (Singh & Kaushik, July 2002). In hot rolling industries of Nepal, Temp core and Thermex system are used for process control. All hot rolling mills have not uniform quality control system. Some mills use automatic control and some have semi-automatic process control. Since the tested samples were from different industries, these samples were collected though out a year so they are from different heats also. One heat have one chemical composition, so there were chances of variations in chemical composition of billets also.

For lower size bars, formation of soft core is difficult due to comparatively fast cooling of shell and core. So, the process control is difficult for lower size bars. Besides cooling process, the chemical composition of billet play important role for yield strength and tensile strength of bars. Most of the billets coming from India, there are many numbers of billet manufactures. So, there is possibility of variation in chemical composition of billet although it is within permissible limit specified in standards.

4.3.1 Distribution of yield strength

A mill-by-mill comparison of average yield strength is presented in Figure 4.17 and Table 4.12 for Fe500 grade TMT bars. From the analysis of tensile test results it is evident that mill GNK has the highest average yield strength 587.8 MPa and mill PSI has the lowest average yield strength 526.5 MPa. The maximum yield strength value was observed for 10 mm bar size of mill SLMR 627.1 MPa and minimum yield strength was observed for mill PSI 506 MPa for 8 mm bar size. Although the lowest value found was comply with the minimum value 500 MPa specified in NS:191. The lowest range of variation for average yield strength was evident for mill PSPT 31.7 MPa and highest range of variation was observed for mill HL 97.9 MPa.

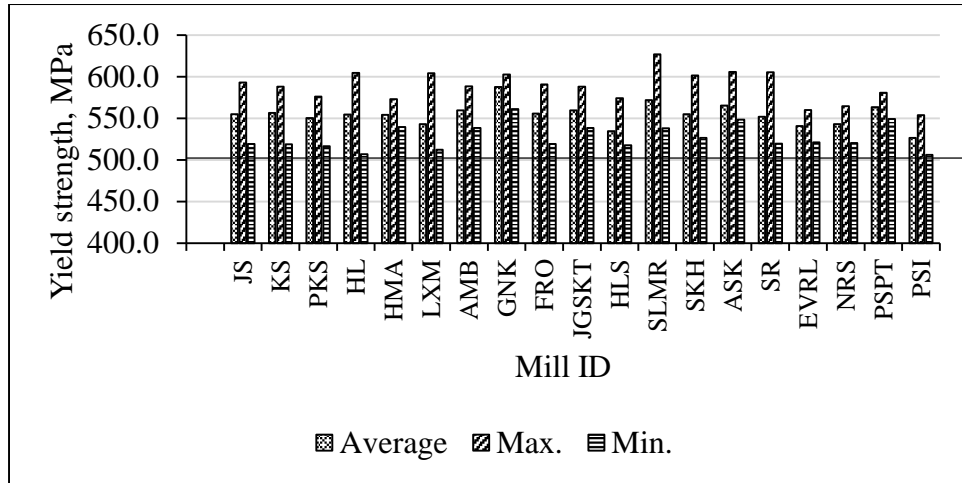


Figure 4.17 Yield strength comparison of individual mill Fe500

Table 4.12 Yield strength for individual mills Fe500 TMT bars

Fe500 TMT Bar, Yield Strength, MPa											
Mill ID	Bar size, mm								Avg.	Max.	Min.
	8	10	12	16	20	25	28	32			
JS	593.0	591.1	562.6	559.5	559.9	519.2	528.8	527.1	555.1	593.0	519.2
KS	588.2	547.3	573.2	564.1	545.7	553.0	563.2	518.8	556.7	588.2	518.8
PKS	566.4	575.4	554.7	552.7	542.0	518.0	576.2	516.6	550.2	576.2	516.6
HL	577.1	604.6	560.0	556.5	576.3	506.9	521.2	533.1	554.5	604.6	506.9
HMA	573.0	549.5	551.3	539.7	550.0	571.6	558.7	540.9	554.3	573.0	539.7
LXM	569.3	531.3	604.3	525.5	554.5	524.9	521.5	512.3	543.0	604.3	512.3
AMB	588.4	574.0	562.7	549.0	545.3	538.5	-	-	559.6	588.4	538.5
GNK	598.3	573.7	602.7	561.0	601.1	590.0	-	-	587.8	602.7	561.0
FRO	590.8	559.7	575.1	551.8	519.0	558.5	534.2	-	555.6	590.8	519.0
JGSKT	543.6	562.0	588.2	558.9	538.3	565.6	-	-	559.4	588.2	538.3
HLS	574.4	541.8	533.4	517.7	521.9	519.2	-	-	534.7	574.4	517.7
SLMR	596.5	627.1	538.1	545.0	561.2	563.5	-	-	571.9	627.1	538.1
SKH	601.6	537.5	526.6	538.6	598.1	527.7	-	-	555.0	601.6	526.6
ASK	605.8	548.6	562.1	553.1	556.9	-	-	-	565.3	605.8	548.6
SR	562.6	605.3	519.5	523.7	548.7	-	-	-	552.0	605.3	519.5
EVRL	554.4	544.6	559.9	524.5	521.2	-	-	-	540.9	559.9	521.2
NRS	564.6	552.8	536.6	541.5	520.4	-	-	-	543.2	564.6	520.4
PSPT	549.1	555.7	557.5	571.2	567.4	580.8	-	-	563.6	580.8	549.1
PSI	506.0	517.2	553.9	517.4	538.1	-	-	-	526.5	553.9	506.0
Avg.	573.9	563.1	559.1	544.8	550.8	545.5	543.4	524.8			
Max.	605.8	627.1	604.3	571.2	601.1	590.0	576.2	540.9			
Min.	506.0	517.2	519.5	517.4	519.0	506.9	521.2	512.3			
NS:191	Min. 500 MPa, Max. Limit not mentioned										

Table 4.13 Yield strength of individual mills Fe500D

Fe500D TMT Bar, Yield Strength, MPa											
Mill ID	Bar size, mm								Avg.	Max.	Min.
	8	10	12	16	20	25	28	32			
RHN	586.6	572.9	547.5	597.2	573.0	576.6	560.5	596.9	576.4	597.2	547.5
KSRB	539.0	512.5	547.1	586.4	569.3	573.6	599.7	551.0	559.8	599.7	512.5
FRO	597.7	560.0	587.1	556.0	520.9	556.6	530.9	-	558.5	597.7	520.9
Avg.	574.4	548.5	560.5	579.8	554.4	569.0	563.7	574.0			
Max.	597.7	572.9	587.1	597.2	573.0	576.6	599.7	596.9			
Min.	539.0	512.5	547.1	556.0	520.9	556.6	530.9	551.0			
NS:191	Min. 500 MPa, Max. Limit not specified										

A mill-by-mill comparison of average yield strength for Fe500D grade TMT bars are presented in Table 4.13. Total 69 numbers of samples from three different brand were tested for tensile properties. From the table it is evident that the lowest average yield strength value were found for mill KSRB 512.5 MPa for 10 mm bar size and maximum average yield strength value were also evident for KSRB 599.7 MPa for 28 mm bar size. The lowest range of variation for average yield strength value were witnessed for mill RHN 49.7 MPa and highest range of variation were witnessed for KSRB 87.2 MPa.

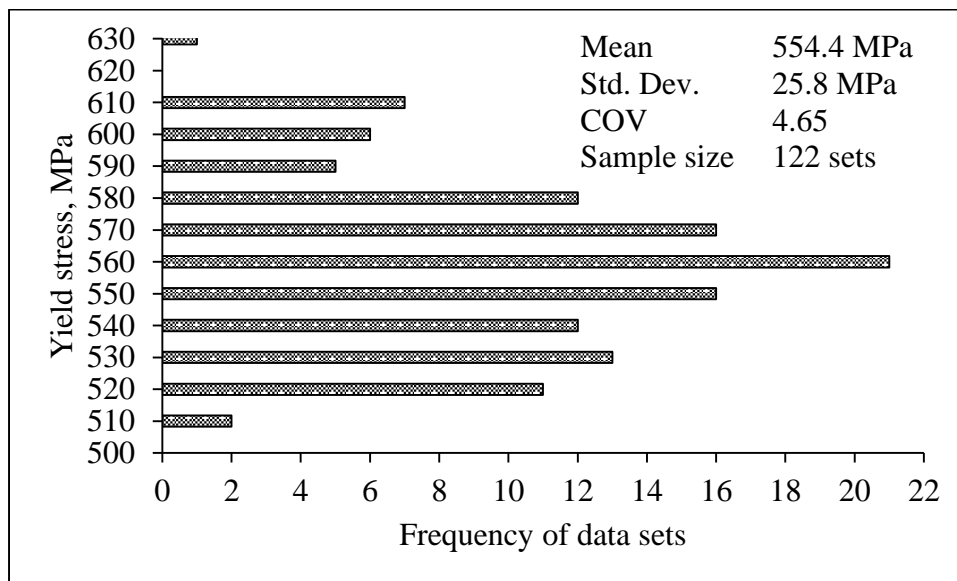


Figure 4.18 Distribution of yield strength of Fe500 TMT bars

Histogram of frequency distributions of yield strength of grade Fe500 TMT bars for different 122 sets of data is shown in Figure 4.18. As can be seen from the figure, the mean yield strength for all the tested samples at NBSM mechanical testing laboratory is 554.4 MPa. From Figure 4.18 it is evident data 22 sets of yield stress value obtained are 560 MPa, 16 sets of yield stress results obtained are 550 MPa and 570 MPa each.

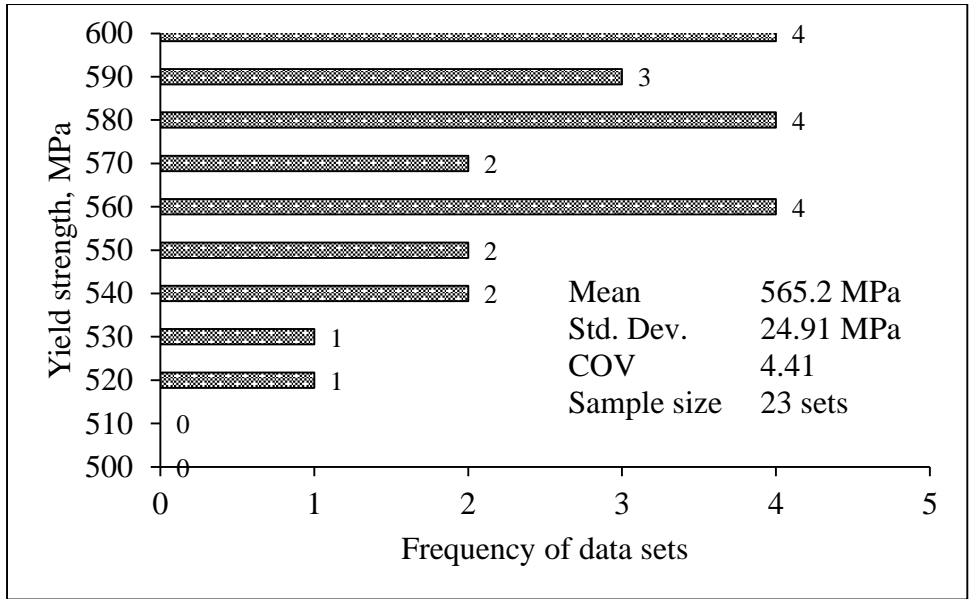


Figure 4.19 Distribution of yield strength of Fe500D TMT bars

Histogram of frequency distributions of yield strength of grade Fe500D TMT bars for different 23 sets of data is shown in Figure 4.19. As can be seen from the figure, the mean yield strength for all the tested samples at NBSM mechanical testing laboratory is 565.2 MPa. From Figure 4.19 it is evident data among the 23 sets of samples the frequency of average yield stress value for 560 MPa, 580 MPa and 600MPa 4 times for each. Similarly, the frequency of yield stress value obtained for 2 times each for 540 MPa, 550 MPa and 570 MPa.

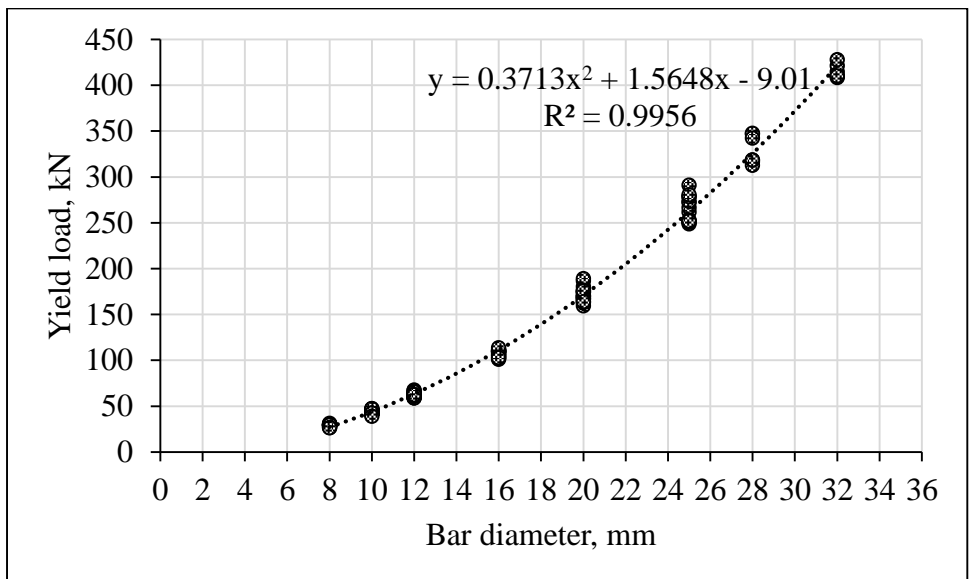


Figure 4.20 Trend line of yield load for different bar diameters Fe500

Data trend line was used to investigate the variation of yield load among different sets of data with variation of bar size. The polynomial equation of second order best fit the data. The R-squared value is 0.9956, which is a good fit. The developed equation from trend line fitting is shown in Figure 4.20 for Fe500 TMT bars.

From Figure 4.20 it is evident that the yield load is increasing upward with respect to diameter of bar. The R-squared value also indicates the perfection of fit line. The value of yield stress is the ratio of yield load to effective cross-section of bar. As the diameter of bar increases its effective cross-sectional area also increases. TMT bars are produced based on its yield strength, so the load bearing capacity of TMT bar are directly proportional to its effective cross-sectional area. The trend line obtained in Figure 4.20 satisfy this relationship between load and bar diameter.

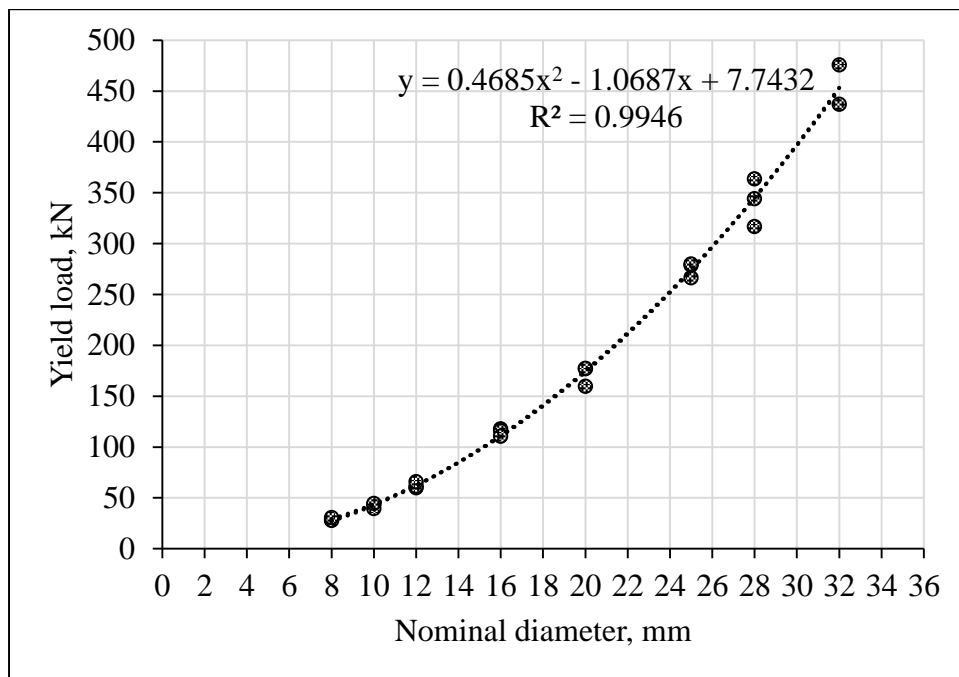


Figure 4.21 Trend line of yield load for different bar diameters Fe500D

Data trend line was used to investigate the variation of yield load among different sets of data with variation of bar size for grade Fe500D. The polynomial equation of second order best fit the data. The R-squared value is 0.9946, which is a good fit. The developed equation from trend line fitting is shown in Figure 4.21 for Fe500D TMT bars. With increase of nominal diameter of TMT bars its effective cross-section of area also increases. Since yield strength is ratio of yield load to effective cross-sectional area, from Figure 4.21 it is evident that the increasing upward trend curve satisfy the yield stress value with respect to nominal diameter of TMT bars.

4.3.2 Distribution of tensile strength

A mill-by-mill comparison of average tensile strength distribution is presented in Table 4.15 and Figure 4.22 below. The tables include the average values obtained from the tested samples of different 19 mills for Fe500 TMT bars and figure shows the average, maximum and minimum values of tensile strength of different rolling mills.

Table 4.14 Tensile strength of individual mill Fe500 TMT bars

Fe500 TMT Bar, Tensile Strength, MPa											
Mill ID	Bar size, mm								Avg.	Max.	Min.
	8	10	12	16	20	25	28	32			
JS	715.7	684.2	660.3	657.1	670.4	639.9	638.8	647.7	664.2	715.7	638.8
KS	710.9	676.6	684.3	665.8	644.6	663.9	681.7	632.3	670.0	710.9	632.3
PKS	685.0	670.4	666.2	656.8	652.3	640.7	676.1	647.4	661.8	685.0	640.7
HL	703.4	704.3	654.4	662.2	692.3	628.6	637.0	648.8	666.4	704.3	628.6
HMA	691.7	680.3	647.6	646.3	657.0	687.8	669.8	657.0	667.2	691.7	646.3
LXM	701.5	641.4	720.5	637.1	672.2	628.5	654.8	640.3	662.0	720.5	628.5
AMB	685.5	661.5	680.8	656.2	674.0	656.0	-	-	669.0	685.5	656.0
GNK	717.3	693.5	681.9	672.4	672.9	674.9	-	-	685.5	717.3	672.4
FRO	690.2	656.5	683.5	672.3	646.5	671.2	661.4		668.8	690.2	646.5
JGSKT	651.7	669.0	680.0	696.8	651.1	682.8	-	-	671.9	696.8	651.1
HLS	705.2	676.8	642.5	626.1	626.0	625.2	-	-	650.3	705.2	625.2
SLMR	682.7	708.9	622.6	641.1	675.9	666.4	-	-	666.3	708.9	622.6
SKH	714.5	642.0	584.6	599.4	698.9	646.9	-	-	647.7	714.5	584.6
ASK	730.3	675.5	671.4	668.5	667.9	-	-	-	682.7	730.3	667.9
SR	698.8	708.4	594.4	605.5	681.0	-	-	-	657.6	708.4	594.4
EVRL	662.5	665.1	668.4	636.9	633.1	-	-	-	653.2	668.4	633.1
NRS	663.7	664.4	661.2	647.6	627.6	-	-	-	652.9	664.4	627.6
PSPT	659.5	672.4	674.9	684.4	675.3	691.6	-	-	676.3	691.6	659.5
PSI	601.6	591.3	643.2	629.7	624.0	-	-	-	618.0	643.2	591.3
Avg.	688.0	670.7	659.1	650.6	660.2	657.5	659.9	645.6			
Max.	730.3	708.9	720.5	696.8	698.9	691.6	681.7	657.0			
Min.	601.6	591.3	584.6	599.4	624.0	625.2	637.0	632.3			
NS: 191	Min. 8 % more than actual YS but not less than 545 MPa, Max. Not specified in standard										

It is evident from Table 4.15 and Figure 4.22 that the highest average tensile strength were observed for mill GNK 685.5 MPa and lowest average tensile strength 618 MPa for mill PSI.

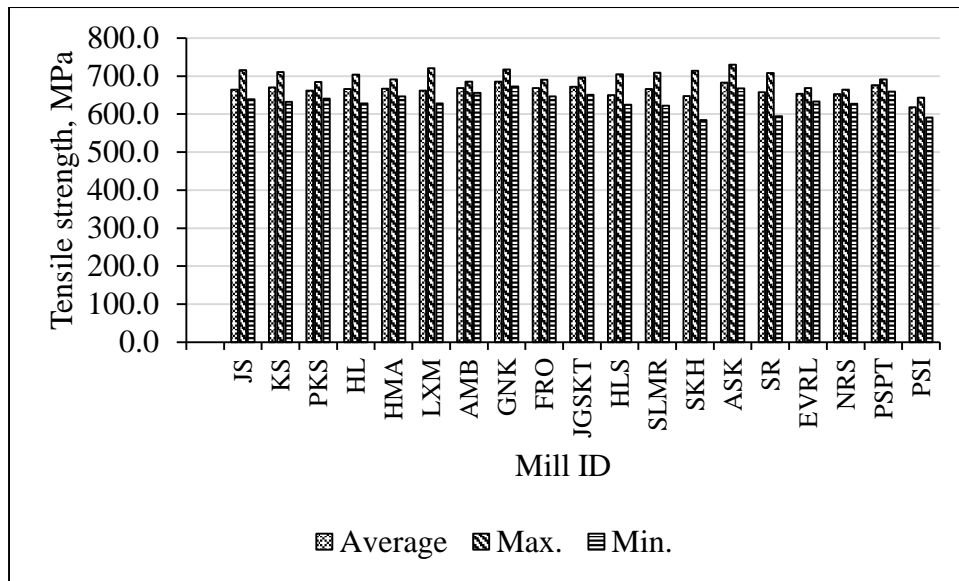


Figure 4.22 Tensile strength for different mills Fe500

The highest tensile strength was witnessed for Mill ASK 730.3 MPa for 8 mm bar size and lowest 584.6 MPa for 12 mm bar size mill SKH. It is also evident that mill AMB has lowest variation in tensile strength for different size that is 29.5 MPa and mill SKH has highest range of variation 130 MPa for average tensile strength.

Table 4.15 Tensile strength of individual mill Fe500D TMT bars

Fe500D TMT Bar, Tensile Strength, MPa											
Mill ID	Bar size, mm								Avg.	Max.	Min.
	8	10	12	16	20	25	28	32			
RHN	700.9	687.8	680.8	716.9	694.8	705.0	683.5	711.2	697.6	716.9	680.8
KSRB	623.9	616.5	661.0	697.7	672.6	688.2	708.7	668.1	667.1	708.7	616.5
FRO	685.7	652.2	695.3	670.9	644.8	671.2	659.1	-	668.5	695.3	644.8
Avg.	670.2	652.1	679.0	695.2	670.7	688.2	683.8	689.6			
Max.	700.9	687.8	695.3	716.9	694.8	705.0	708.7	711.2			
Min.	623.9	616.5	661.0	670.9	644.8	671.2	659.1	668.1			
NS: 191	Min. 10.0% more than actual YS but not less than 565 MPa, Max. Not specified in standard										

A mill- by-mill comparison of average tensile strength for Fe500D grade TMT bars are shown in Table 4.16. From the table it is evident that mill RHN has highest average tensile strength value 697.6 MPa and mill KSRB has lowest average tensile strength value 667.1 MPa. The minimum tensile strength value were witnessed for KSRB 10 mm bar size 616.5 MPa and maximum tensile strength value were observed for mill RHN 716.9 MPa for 16 mm bar size.

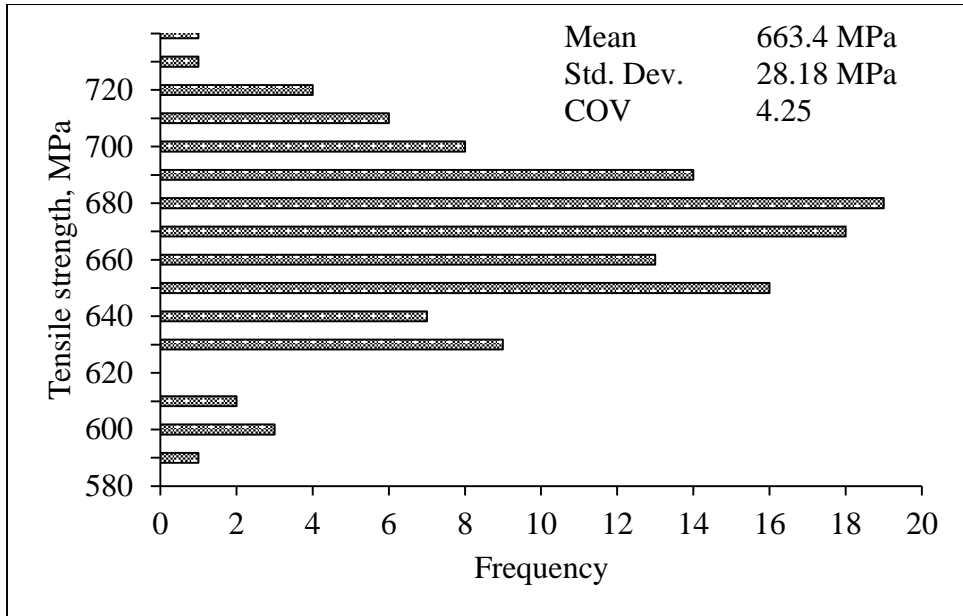


Figure 4.23 Distribution of tensile strength of Fe500 TMT bars

Distributions of tensile strength of grade Fe500 TMT bars for different sets of data is shown in Figure 4.23. As can be seen from the figure, the mean tensile strength for all the tested samples at NBSM mechanical testing laboratory is 663.4 MPa. From Figure 4.23 it is evident data 20 sets of tensile strength value obtained are 680 MPa, 18 sets of tensile strength results obtained are 670 MPa and 16 sets of tensile strength results obtained are 650 MPa each.

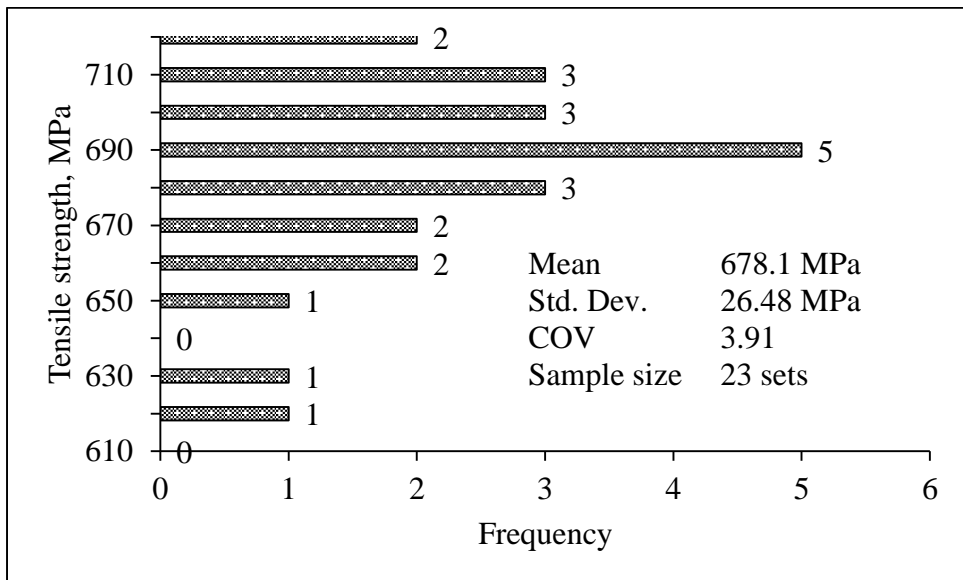


Figure 4.24 Distribution of tensile strength of Fe500D TMT bars

Histogram of frequency distributions of tensile strength of grade Fe500D TMT bars for different 23 sets of data is shown in Figure 4.24. As can be seen from the figure, the

mean tensile strength for all the tested samples at NBSM mechanical testing laboratory is 678.1 MPa. From Figure 4.24 it is evident data among the 23 sets of samples the frequency of average tensile strength value for 680 MPa, 700 MPa and 710 MPa three times for each. Similarly, the frequency of tensile strength value obtained for two times each for 660 MPa, 670 MPa and 720 MPa. Among the tested samples 690 MPa tensile strength value was found for five times.

4.3.3 Distribution of percentage elongation

During initial period of reinforced concrete construction, requirement of ductility was considered synonymous with bendability. However, ductility of reinforcement has been found to have far reaching effects on the safety and durability of the structure. The physical property of reinforced bar, which is responsible for ductility, is its elongation. Ductility refers to ability of dissipating energy and large deformation.

A mill-by-mill comparison of tensile test data for percentage elongation is presented in Figure 4.25 and Table 4.16 for Fe500 grade TMT bars. The tables include the average values obtained from the tested samples of different 19 mills for Fe500 TMT bars.

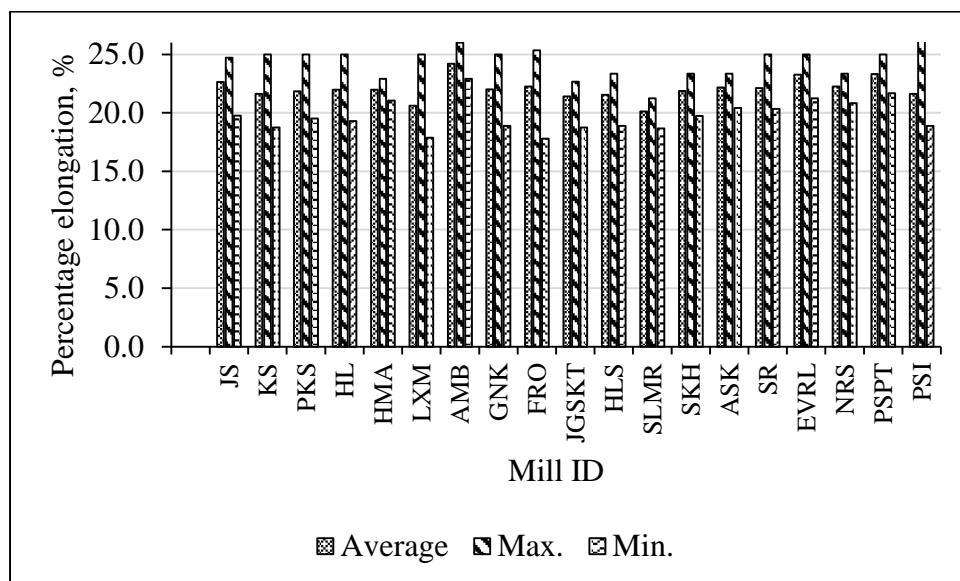


Figure 4.25 Percentage elongation for rolling mill Fe500

It is evident that the highest average value of percentage elongation was observed for mill AMB 24.2% and lowest average percentage elongation were observed for mill FRO 17.8%. The lowest percentage elongation value were determined 17.8% for bar size 12 mm of mill FRO and highest percentage elongation value 26.7% for 8 mm bar size of mill PSI. The highest range of variation for percentage elongation was observed

for mill PSI 7.8 percent among the different size and lowest range of variation 1.9 percent were observed for mill HMA.

Table 4.16 Percentage elongation of individual mill Fe500 TMT bars

Fe500 TMT Bar, Percentage Elongation, %											
Mill ID	Bar size, mm								Average	Max.	Min.
	8	10	12	16	20	25	28	32			
JS	22.5	22.7	23.3	23.8	22.7	24.7	19.8	21.7	22.6	24.7	19.8
KS	25.0	20.7	20.6	21.3	23.7	21.9	21.2	18.8	21.6	25.0	18.8
PKS	25.0	21.3	22.2	20.8	21.3	22.2	19.5	22.3	21.8	25.0	19.5
HL	22.5	21.3	22.8	22.9	21.0	25.0	19.3	21.0	22.0	25.0	19.3
HMA	22.5	21.3	22.2	22.9	21.7	22.5	21.7	21.0	22.0	22.9	21.0
LXM	25.0	20.7	18.3	21.7	19.7	21.9	17.9	19.8	20.6	25.0	17.9
AMB	22.9	24.7	25.0	22.9	26.0	23.6	-	-	24.2	26.0	22.9
GNK	22.5	21.3	25.0	23.3	21.0	18.9	-	-	22.0	25.0	18.9
FRO	21.7	25.3	17.8	22.9	24.0	22.2	21.9	-	22.3	25.3	17.8
JGSKT	21.7	22.7	22.2	18.8	20.7	22.5	-	-	21.4	22.7	18.8
HLS	21.7	20.7	18.9	23.3	21.7	23.1	-	-	21.5	23.3	18.9
SLMR	20.8	20.0	19.4	21.3	18.7	20.6	-	-	20.1	21.3	18.7
SKH	23.3	22.0	23.3	22.1	20.7	19.7	-	-	21.9	23.3	19.7
ASK	23.3	22.0	22.8	20.4	22.3	-	-	-	22.2	23.3	20.4
SR	25.0	22.0	21.1	22.1	20.3	-	-	-	22.1	25.0	20.3
EVRL	23.3	24.0	25.0	21.3	22.7	-	-	-	23.3	25.0	21.3
NRS	23.3	21.3	22.8	20.8	23.0	-	-	-	22.3	23.3	20.8
PSPT	25.0	24.7	25.0	21.7	21.7	21.9	-	-	23.3	25.0	21.7
PSI	26.7	20.7	18.9	21.3	20.7	-	-	-	21.6	26.7	18.9
Average	23.4	22.1	21.9	21.9	21.8	22.2	20.2	20.8			
Max.	26.7	25.3	25.0	23.8	26.0	25.0	21.9	22.3			
Min.	20.8	20.0	17.8	18.8	18.7	18.9	17.9	18.8			
NS: 191	Min. on gauge length $5.65\sqrt{A}$, 12.0 %, Max. limit not specified in standard										

In hot rolling mills, the bars leaves the quench box with temperature gradient through its cross-section. As the bar cools, heat flows from the bar's center to its surface so that the bars's heat and pressure correctly tempers an intermediate ring of martensite and bainite. Finally, the slow cooling after quenching automatically tempers the austenitic core to ferrite and pearlite on the cooling bed. These bars, therefore, exhibit a variation in microstructure in their cross-section, having strong, tough, tempered martensite in the surface layer of the bar, where as an intermediate layer of martensite and bainite, and a refined, tough and ductile ferrite and pearlite. The soft ferrite-pearlite core enables

the bar ductility to bear dynamic and seismic loading. The value of percentage elongation depends directly on chemical composition of billet, and tensile strength of bars. Higher the tensile strength value bars have lower elongation.

Table 4.17 Percentage elongation of individual mill Fe500D TMT bars

Fe500D TMT Bar, Percentage Elongation, %											
Mill ID	Bar size, mm								Average	Max.	Min.
	8	10	12	16	20	25	28	32			
RHN	25.0	23.3	22.8	22.9	21.3	19.4	19.8	21.3	22.0	25.0	19.4
KSRB	24.2	22.7	22.8	19.6	20.3	22.8	20.2	21.3	21.7	24.2	19.6
FRO	21.7	22.7	21.1	22.9	23.7	22.5	21.4	-	22.3	23.7	21.1
Average	23.6	22.9	22.2	21.8	21.8	21.6	20.5	21.3			
Max.	25.0	23.3	22.8	22.9	23.7	22.8	21.4	21.3			
Min.	21.7	22.7	21.1	19.6	20.3	19.4	19.8	21.3			
NS: 191	Min. on gauge length $5.65\sqrt{A}$, 16.0%, Max. limit not specified in standard										

A mill-by-mill comparison of percentage elongation value for Fe500D grade TMT bars are presented in Table 4.17. From the table and tested data it is evident that mill FRO has the highest average percentage elongation value 22.3% and mill KSRB has the lowest average percentage elongation value 21.7%. The range of variation for mill RHN were observed largest and lowest for mill FRO. The lowest percentage elongation value were found 19.4% for 25 mm bar size of mill RHN and highest percentage elongation were found for 8 mm bar size of mill RHN.

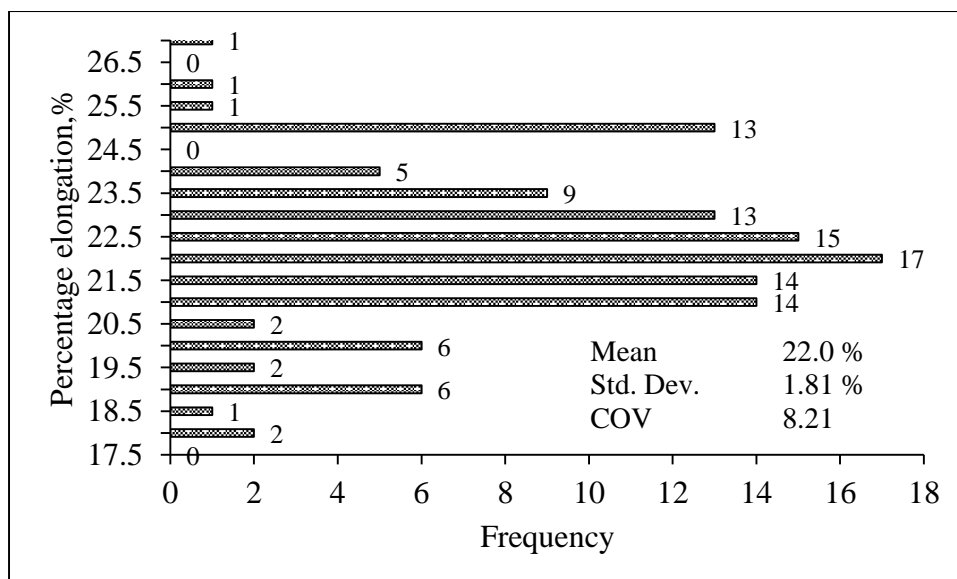


Figure 4.26 Distribution of avg. percentage elongation Fe500 TMT bars

Histogram for frequency distributions of average percentage elongation of grade Fe500 TMT bars for different 122 sets of data is shown in Figure 4.26. As can be seen from the figure, the mean percentage elongation for all the tested samples is 22.0%. From Figure 4.26 it is evident data among the 122 sets of samples the frequency of average percentage elongation value for 21.0% and 21.5% are 14 times for each. Similarly, the frequency of percentage elongation value obtained for 13 times each for 23.0% and 25.0%. Among the tested samples 22.0% percentage elongation value was found for 17 sets of samples.

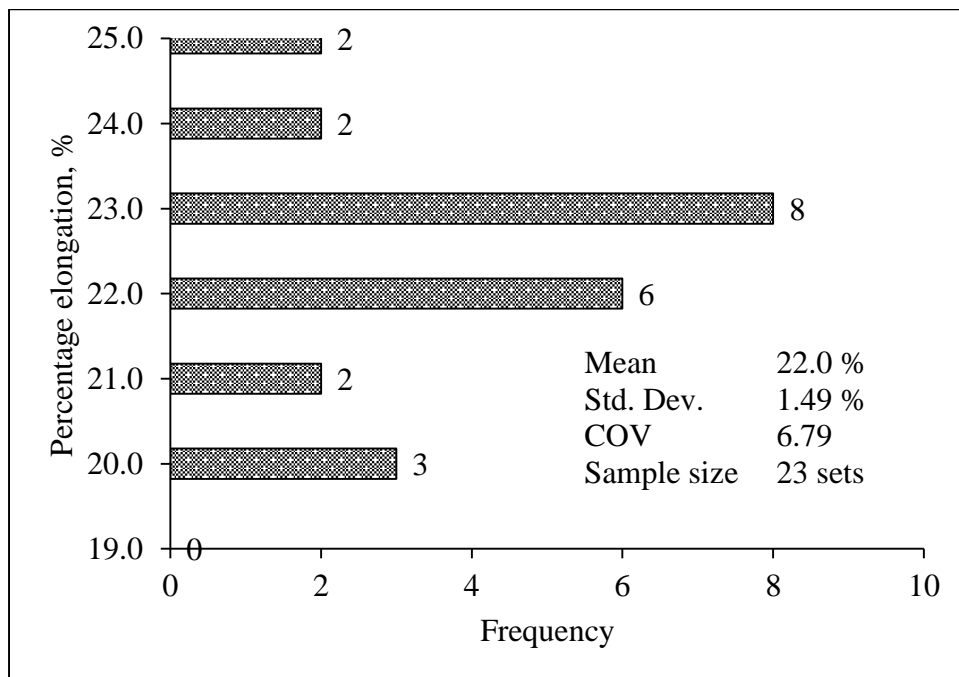


Figure 4.27 Distribution of avg. percentage elongation Fe500D TMT bars

Histogram for frequency distributions of average percentage elongation of grade Fe500D TMT bars for different 23 sets of data is shown in Figure 4.27. As can be seen from the figure, the mean percentage elongation for all the tested samples is 22.0%. From Figure 4.27 it is evident data among the 23 sets of samples the frequency of average percentage elongation value of 23.0% found for 8 sets of samples. Similarly, the frequency of percentage elongation value obtained for 6 sets of samples was 22.0%.

4.3.4 Distribution of UTS/YS ratio

Ensuring a minimum UTS/YS ratio is important as the maximum strength capacity of structural members should be distinct from its yield strength. This helps in realizing the

assumed failure mechanism and distributing inelastic activities across various elements of structure. The seismic response of reinforced concrete structures, to a great extent, depends upon the ductile detailing of reinforcement. The Indian Standard (IS 13920, 2016) pertains to the ductile detailing aspect of the reinforcement in RC structures. The minimum UTS/YS ratio is 1.15 and Maximum UTS/YS ratio to 1.25 specified in IS: 13920. In NS:191, there is no any mentioned about UTS/YS ratio.

A mill-by-mill comparison of average UTS/YS ratio distribution is presented in Table 4.18 and Figure 4.28 for Fe500 grade TMT bars of nineteen rolling mills.

Table 4.18 UTS/YS ratio for individual mill Fe500 TMT bars

Fe500 TMT Bar, UTS/YS Value											
Mill ID	Bar Size, mm								Average	Max.	Min.
	8	10	12	16	20	25	28	32			
JS	1.21	1.16	1.18	1.17	1.20	1.23	1.21	1.23	1.20	1.23	1.16
KS	1.21	1.24	1.19	1.18	1.18	1.20	1.21	1.22	1.20	1.24	1.18
PKS	1.21	1.16	1.20	1.19	1.20	1.24	1.18	1.25	1.20	1.25	1.16
HL	1.22	1.17	1.17	1.19	1.20	1.24	1.22	1.22	1.20	1.24	1.17
HMA	1.21	1.24	1.17	1.20	1.19	1.20	1.20	1.21	1.20	1.24	1.17
LXM	1.23	1.21	1.19	1.21	1.21	1.20	1.26	1.25	1.22	1.26	1.19
AMB	1.16	1.15	1.21	1.20	1.24	1.22	-	-	1.20	1.24	1.15
GNK	1.20	1.21	1.14	1.20	1.12	1.14	-	-	1.17	1.21	1.12
FRO	1.17	1.17	1.19	1.22	1.25	1.20	1.24	-	1.21	1.25	1.17
JGSKT	1.20	1.19	1.16	1.25	1.21	1.21	-	-	1.20	1.25	1.16
HLS	1.23	1.25	1.20	1.21	1.20	1.20	-	-	1.22	1.25	1.20
SLMR	1.15	1.13	1.16	1.18	1.21	1.18	-	-	1.17	1.21	1.13
SKH	1.19	1.20	1.11	1.11	1.17	1.23	-	-	1.17	1.23	1.11
ASK	1.21	1.23	1.19	1.21	1.20	-	-	-	1.21	1.23	1.19
SR	1.24	1.17	1.14	1.16	1.24	-	-	-	1.19	1.24	1.14
EVRL	1.20	1.22	1.19	1.21	1.21	-	-	-	1.21	1.22	1.19
NRS	1.18	1.20	1.23	1.20	1.21	-	-	-	1.20	1.23	1.18
PSPT	1.20	1.21	1.21	1.20	1.19	1.19	-	-	1.20	1.21	1.19
PSI	1.19	1.14	1.16	1.22	1.16	-	-	-	1.17	1.22	1.14
Average	1.20	1.19	1.18	1.19	1.20	1.21	1.22	1.23			
Max.	1.24	1.25	1.23	1.25	1.25	1.24	1.26	1.25			
Min.	1.15	1.13	1.11	1.11	1.12	1.14	1.18	1.21			
NS: 191	Value not specified in product standard										

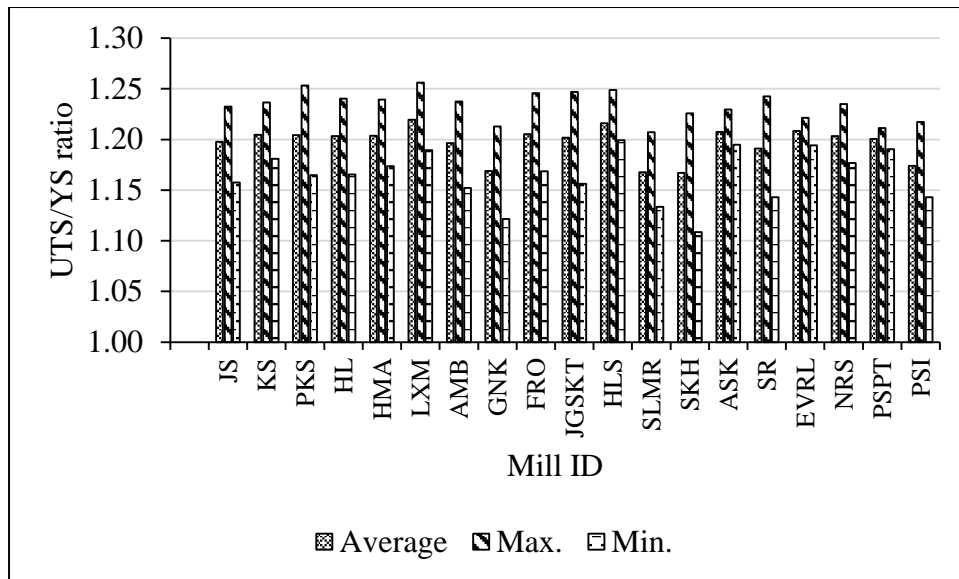


Figure 4.28 UTS/YS ratio for individual rolling mill Fe500

From Table 4.18 and Figure 4.28 it is evident that the highest average UTS/YS ratio value 1.22 was observed for mill LXM and lowest UTS/YS ratio value 1.17 was observed for mill GNK, SLMR, SKH and PSI. The lowest UTS/YS ratio value 1.11 for 12 mm and 16 mm bar size of mill SKH and highest UTS/YS ratio value 1.26 for 28 mm bar size of mill LXM were observed.

Table 4.19 UTS/YS ratio for individual mill Fe500D TMT bars

Fe500D TMT Bar, UTS/YS Value											
Mill ID	Bar Size, mm								Average	Max.	Min.
	8	10	12	16	20	25	28	32			
RHN	1.19	1.20	1.24	1.20	1.21	1.22	1.22	1.19	1.21	1.24	1.19
KSRB	1.16	1.20	1.21	1.19	1.18	1.20	1.18	1.21	1.19	1.21	1.16
FRO	1.15	1.16	1.18	1.21	1.24	1.21	1.24	-	1.20	1.24	1.15
Average	1.17	1.19	1.21	1.20	1.21	1.21	1.21	1.20			
Max.	1.19	1.20	1.24	1.21	1.24	1.22	1.24	1.21			
Min.	1.15	1.16	1.18	1.19	1.18	1.20	1.18	1.19			
NS: 191	Value not specified in product standard										

A mill-by-mill comparison for Fe500D grade TMT bars are presented in Table 4.19. From test result data it is observed that mill KSRB has lowest average UTS/YS ratio value 1.19 and mill RHN has highest average UTS/YS ratio value 1.21. The highest range of variation for mill FRO for different bar size were witnessed. For all bar size the UTS/YS ratio value were found above 1.15.

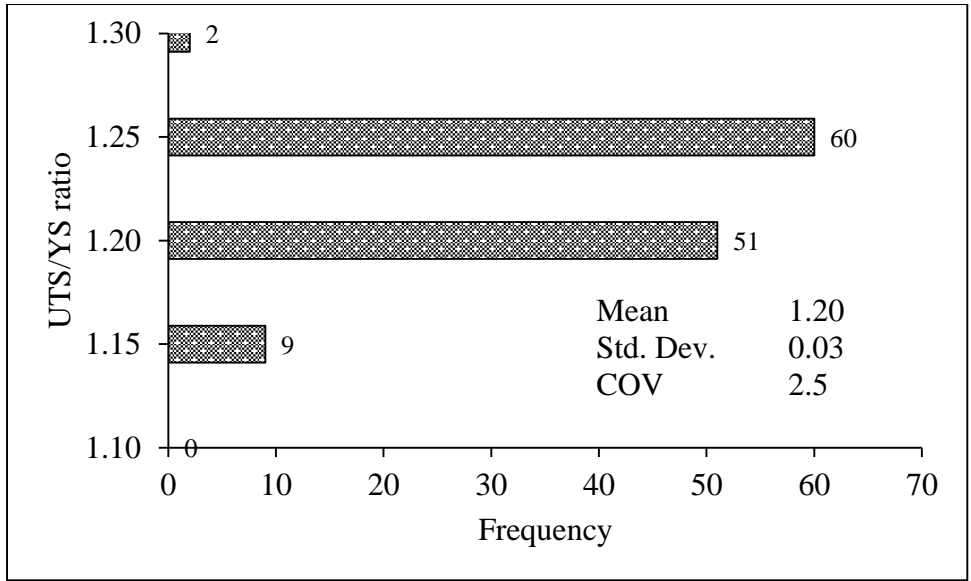


Figure 4.29 Distribution of avg. UTS/YS ratio Fe500 TMT bars

Histogram of frequency distributions of UTS/YS ratio of grade Fe500 TMT bars for different 122 sets of data is shown in Figure 4.29. As can be seen from the figure, the mean UTS/YS ratio for all the tested samples at NBSM mechanical testing laboratory is 1.20. From Figure 4.29 it is evident data among the 122 sets of samples the frequency of average UTS/YS ratio value for 1.20 was found for 51 sets of sample and UTS/YS ratio value 1.25 was found for 60 sets of samples. The frequency of UTS/YS ratio value 1.15 was found for 9 sets of sample and 1.3 for 2 sets of samples.

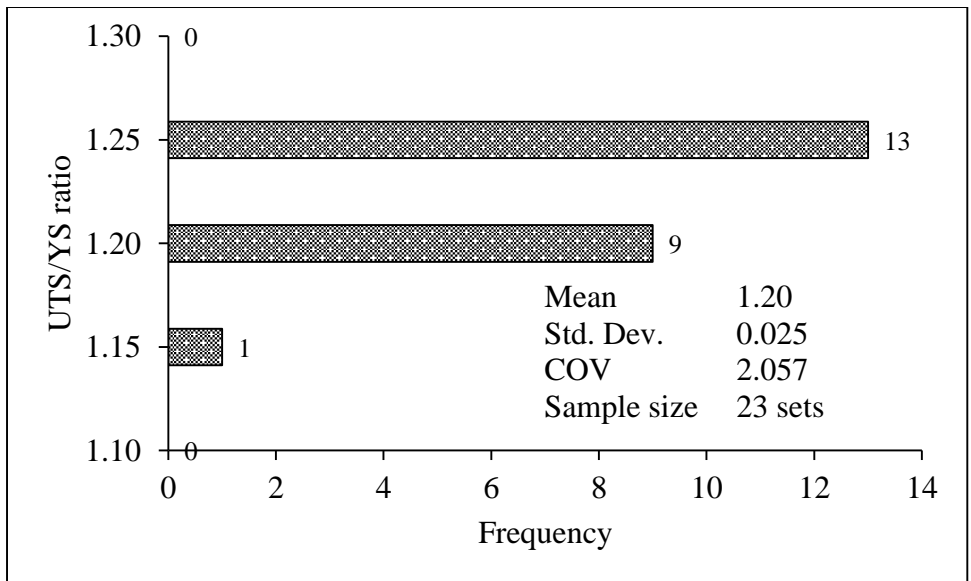


Figure 4.30 Distribution of average UTS/YS ratio Fe500D TMT bars

Histogram for frequency distributions of average UTS/YS ratio of grade Fe500D TMT bars for different 23 sets of data is shown in Figure 4.30. As can be seen from the figure, the mean UTS/YS ratio for all the tested samples is 1.20. From Figure 4.30 it is evident data among the 23 sets of samples the frequency of average UTS/YS ratio value of 1.25 was found for 13 sets of samples. Similarly, the frequency of UTS/YS ratio value obtained for 9 sets of samples was 1.25. One sample set has UTS/YS ratio value 1.15.

4.3.5 Distribution of bond value

External ribs running across the entire length of the TMT bar give bonding strength between the bar and the concrete. Rib also inhibits longitudinal movement of the bar relative to concrete which surrounds the bar in construction works. Higher bond value indicates the stronger bond and less movement of bar within the RC structure. Rollers which is designed to fulfill the value of specified bond value for different size of bars. Patterns of ribs are prepared on the outer periphery of the roller to confirm projected area with standard. These rollers are continuous moving parts during the hot rolling process. After certain time interval, the depth of grooves fills with hot slag and some wear of grooves during the hot rolling process. So the value of height and length of transverse rib may change after continuous use of rollers for long period of time. So it is the responsibility of quality control department of concerned hot rolling mill to change rollers at specified interval.

A mill-by-mill comparison of bond value distribution is presented in Tables 4.21 and 4.22 for Fe500 and Fe500D grade TMT bars respectively. The tables include the bond values obtained from the tested samples of different 19 mills for Fe500 TMT bars and three mills for Fe500D grade. The bond value were determined by area of projection method.

The highest range of variation for 16 mm bar size and lowest for 32 mm bar size were observed. For bar size 16 mm highest range of variation 2.82 times more than the lowest bond value were observed. The lowest range of variation 1.45 time for bar size 32 mm were observed. For bar size of lower diameter 8 mm, 10 mm, 12 mm and 16 mm the variation in bond value more than 2 times were observed. For bar size 20 mm, 25 mm and 28 mm the range of variation were found up to 1.90 times than the lowest measured values.

Table 4.20 Bond value for individual mill Fe500 TMT bars

Fe500 TMT Bar, Bond Value, mm								
Mill ID	Bar size, mm							
	8	10	12	16	20	25	28	32
JS	2.89	2.33	3.65	4.12	4.73	5.51	5.69	6.04
KS	1.25	2.05	2.61	4.30	5.14	5.03	4.95	7.29
PKS	1.54	1.98	1.88	1.95	4.63	4.86	4.81	5.55
HL	1.53	2.19	3.18	4.73	4.45	5.22	5.99	5.53
HMA	1.48	1.36	2.68	3.17	3.67	4.25	6.11	6.20
LXM	1.86	2.09	2.98	4.08	4.61	6.12	7.44	7.99
AMB	1.06	1.17	1.80	2.51	3.42	4.80	-	-
GNK	1.23	2.02	3.13	5.48	6.49	5.19	-	-
FRO	1.41	2.15	2.45	4.03	5.58	6.34	6.82	
JGSKT	2.00	2.23	2.38	3.54	5.04	4.30	-	-
HLS	2.26	1.95	3.57	4.33	5.05	4.46	-	-
SLMR	2.28	2.59	3.67	5.23	5.73	7.72	-	-
SKH	1.74	2.00	2.58	3.56	4.32	4.76	-	-
ASK	2.00	2.10	2.01	4.15	5.66	-	-	-
SR	1.11	1.24	1.78	3.00	3.79	-	-	-
EVRL	1.76	1.47	1.80	2.42	3.77	-	-	-
NRS	1.50	1.80	2.88	2.38	3.81	-	-	-
PSPT	1.97	1.84	2.19	2.98	3.77	4.68	-	-
PSI	1.33	2.18	3.04	3.33	3.58	-	-	-
Average	1.69	1.93	2.65	3.65	4.59	5.23	5.97	6.43
Max.	2.89	2.59	3.67	5.48	6.49	7.72	7.44	7.99
Min.	1.06	1.17	1.78	1.95	3.42	4.25	4.81	5.53
NS: 191	0.96	1.2	1.8	2.4	3.4	4.25	4.76	5.44

Table 4.21 Bond value for individual mill Fe500D TMT bars

Fe 500D TMT Bar, Bond Value, mm								
Mill ID	Bar size, mm							
	8	10	12	16	20	25	28	32
RHN	1.06	2.35	3.33	3.56	4.62	4.78	5.76	6.58
KSRB	1.14	1.78	4.49	2.80	5.11	6.00	5.15	7.16
FRO	1.70	2.34	2.60	4.37	5.10	5.79	6.39	-
Average	1.30	2.16	3.47	3.57	4.95	5.52	5.77	6.87
Max.	1.70	2.35	4.49	4.37	5.11	6.00	6.39	7.16
Min.	1.06	1.78	2.60	2.80	4.62	4.78	5.15	6.58
NS: 191	0.96	1.2	1.8	2.4	3.4	4.25	4.76	5.44

4.3.6 Distribution of mass per meter run

Mass and length of the collected samples were taken first. With the help of these two parameters gross cross-sectional area of deformed bar were calculated. That calculated area were used for marking gauge length for percentage elongation, and for calculation of yield strength and tensile strength. Mass per meter run is one of the important parameters for rolling mills for process control adjustment. It determines the nominal size of bars and equalizing temperature set up for process control.

The primary criteria to be satisfied by the steel bars are the mass per meter run. The IS 1786/NS:191 specifies batch rolling tolerances in the range of ± 7 to 3 percent depending on the diameter of the bars. It is very well possible to control the weight of the deformed bars within these limits and if it is specified that steel should be supplied in the minus tolerances range only then substantial savings in the weight of steel could be effected. It is possible to save up to 7 percent of the cost of steel (Singh & Kaushik, July 2002). For individual sample plus tolerance is not specified. Lower tolerance for individual samples in the range of -8 to -4 percent depending on the diameter of bar. It is very well possible to control the weight of the bars within these limits.

Table 4.22 Average mass per meter run for individual mill Fe500D TMT bars

Fe500D TMT bar, mass per meter run, kg/m								
Mill ID	Bar size, mm							
	8	10	12	16	20	25	28	32
RHN	0.381	0.598	0.860	1.550	2.426	3.791	4.820	6.254
KSRB	0.406	0.602	0.882	1.551	2.445	3.832	4.760	6.230
FRO	0.403	0.624	0.882	1.562	2.409	3.754	4.685	-
Mean	0.397	0.608	0.875	1.554	2.427	3.793	4.755	6.242
Max.	0.406	0.624	0.882	1.562	2.445	3.832	4.820	6.254
Min.	0.381	0.598	0.860	1.550	2.409	3.754	4.685	6.230
NS:191	0.395	0.617	0.888	1.580	2.470	3.850	4.830	6.310
NS, Min.	0.363	0.568	0.835	1.485	2.371	3.696	4.637	6.058

A mill-by-mill comparison of average mass per meter run distribution is presented in Tables 4.22 and 4.23 respectively for Fe500D and Fe500 TMT bars. The tables include the average mass per meter run obtained from the tested samples of different 19 mills for Fe500 TMT bars and three mills for Fe500D grade. The mass per meter run were

determined by taking weight and length of the collected sample with the precision limit of instruments specified in product standard.

Table 4.23 Average mass per meter run for individual mill Fe500 TMT bars

Fe500 TMT bar, mass per meter run, kg/m								
Mill ID	Bar size, mm							
	8	10	12	16	20	25	28	32
JS	0.394	0.611	0.894	1.551	2.440	3.807	4.702	6.177
KS	0.402	0.594	0.868	1.552	2.440	3.863	4.840	6.182
PKS	0.389	0.606	0.889	1.561	2.449	3.803	4.734	6.236
HL	0.395	0.601	0.885	1.553	2.457	3.856	4.715	6.206
HMA	0.407	0.604	0.871	1.545	2.437	3.822	4.817	6.213
LXM	0.404	0.611	0.876	1.570	2.414	3.749	4.793	6.286
AMB	0.395	0.597	0.864	1.544	2.409	3.817	-	-
GNK	0.379	0.594	0.873	1.539	2.438	3.874	-	-
FRO	0.403	0.625	0.887	1.558	2.411	3.749	4.682	-
JGSKT	0.389	0.593	0.875	1.565	2.440	3.797	-	-
HLS	0.389	0.599	0.872	1.547	2.449	3.825	-	-
SLMR	0.387	0.592	0.874	1.541	2.437	3.883	-	-
SKH	0.411	0.627	0.884	1.537	2.482	3.749	-	-
ASK	0.398	0.604	0.879	1.565	2.471	-	-	-
SR	0.411	0.616	0.892	1.519	2.526	-	-	-
EVRL	0.407	0.608	0.875	1.548	2.472	-	-	-
NRS	0.410	0.603	0.889	1.577	2.518	-	-	-
PSPT	0.385	0.600	0.870	1.564	2.434	3.793	-	-
PSI	0.409	0.593	0.887	1.561	2.392	-	-	-
Average	0.398	0.604	0.879	1.553	2.448	3.813	4.755	6.217
Max.	0.411	0.627	0.894	1.577	2.526	3.883	4.840	6.286
Min.	0.379	0.592	0.864	1.519	2.392	3.749	4.682	6.177
NS:191	0.395	0.617	0.888	1.580	2.470	3.850	4.830	6.310
NS, Min.	0.363	0.568	0.835	1.485	2.371	3.696	4.637	6.058

From tables of average mass per meter run for all mills it is evident that there is less variation for all bar sizes and mills. The ratio between maximum and minimum value of mass per meter run for 8 mm bar size were found 1.08 which is highest among all bar size and lowest ratio 1.01 for 32 mm bar size. For the bar size 12 mm, 16 mm, 25 mm and 28 mm the ratio was found 1.03. Higher ratio indicates the higher range of variation.

4.3.7 Distribution of total elongation at maximum force

A mill-by-mill comparison of average total elongation at maximum force distribution is presented in Table 4.25. The tables include the average values obtained from the tested samples of different three mills for Fe500D grade.

It is evident from Table 4.25 that mill FRO has the lowest average total elongation at maximum force of all mills for grade Fe500D and mill RHN has highest average total elongation at maximum force for Fe500D TMT bars. The large range of variation were found for mill KSRB and lowest range of variation for mill FRO. The maximum value 12.1% for bar of size 12 mm of mill RHN and lowest 5.3% for bar size 8 mm of mill FRO were observed.

Table 4.24 Average total elongation at max. Force Fe500D TMT bars

Fe500D TMT bar, total elongation at max. force, %											
Mill ID	Bar size, mm								Average	Max.	Min.
	8	10	12	16	20	25	28	32			
RHN	7.35	7.76	12.09	10.60	8.20	7.30	7.33	10.49	8.9	12.1	7.3
KSRB	5.73	6.12	11.03	6.79	7.34	8.77	9.40	9.29	8.1	11.0	5.7
FRO	5.34	5.66	9.76	8.60	9.21	8.11	7.95	-	7.8	9.8	5.3
Average	6.1	6.5	11.0	8.7	8.3	8.1	8.2	9.9			
Max.	7.4	7.8	12.1	10.6	9.2	8.8	9.4	10.5			
Min.	5.3	5.7	9.8	6.8	7.3	7.3	7.3	9.3			
NS: 191	Min. 5.0%, Max. limit not specified in standard										

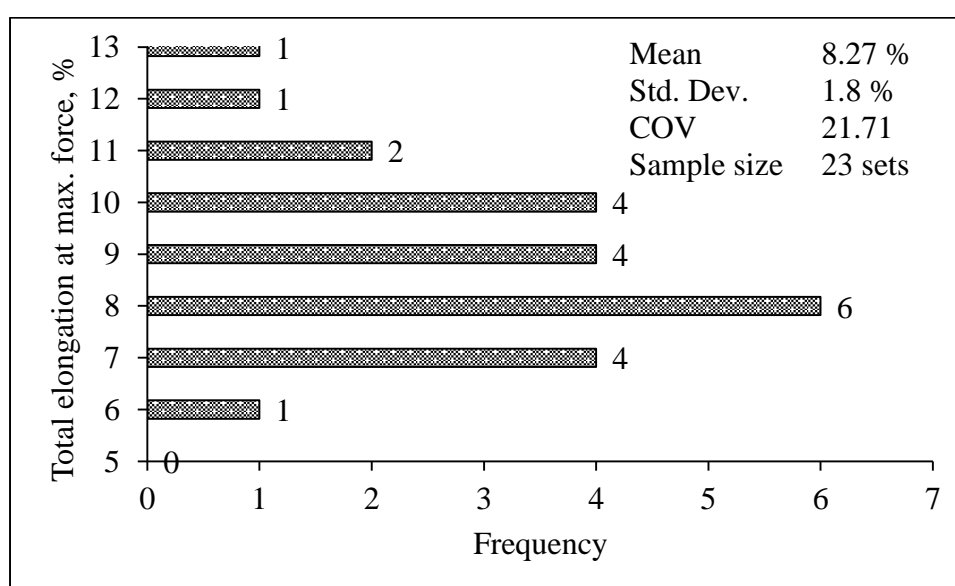


Figure 4.31 Distribution of total elongation at max force Fe500D TMT bars

Histogram for frequency distributions of average total elongation at maximum force of grade Fe500D TMT bars for different 23 sets of data is shown in Figure 4.19. As can be seen from the figure, the mean total elongation at maximum force value for all the tested samples is 8.27 percent. From Figure 4.19 it is evident data among the 23 sets of samples the frequency of average total elongation at maximum force value of 8% was found for 6 sets of samples. Similarly, the frequency of total elongation at maximum force value obtained for 4 sets of samples was 7%, 9% and 10% each. The total elongation at maximum force value of 6%, 12% and 13% was found for one set. The value of COV is high. Basically COV value less than 10 is very good, 20-30 is acceptable, and COV value greater than 30 is not acceptable.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

This study was undertaken to gain an understanding of the variability of the mechanical properties of reinforced bars manufactured across Nepal and certified with NS mark. The data were generated by conducting mechanical tests on the collected samples at NBSM mechanical testing laboratory. All the samples were tested based on the standard test method specified in standards.

5.1 Conclusions

Based on these results and discussions, the following conclusions are made:

The mean value of mechanical properties of tested samples are:

- The mean yield strength of Fe500 TMT bars were found 554.4 MPa with minimum value 506.0 MPa and maximum value 627.0 MPa. The mean value of yield strength for Fe500D grade bars were calculated 565.2 MPa with minimum value 512.5 MPa and maximum value 599.7 MPa.
- The mean value of tensile strength of Fe500 TMT bars samples were found 663.4 MPa with minimum value 584.6 MPa and maximum value 730.3 MPa. The mean value of tensile strength of Fe500D TMT bars samples were found 678.1 MPa with minimum value 616.5 MPa and maximum value 716.9 MPa.
- The mean value of percentage elongation for Fe500 TMT bars were obtained 22.0% with minimum value 17.8% and maximum value 26.7%. The mean value of percentage elongation of Fe500D samples were calculated 22.0% with minimum value 19.4% and maximum value 25%.
- The mean value of UTS/YS ratio of Fe500 TMT bars were found 1.20 with minimum value 1.11 and maximum value 1.26. The mean value of UTS/YS ratio of Fe500D TMT bars were found 1.2 with minimum value 1.15 and maximum value 1.24.
- The mean value of total elongation at maximum force were calculate from tested samples of Fe500D were 8.27% with minimum value 5.34% and maximum value 12%.

Yield strength, tensile strength, percentage elongation, mass per meter run, total elongation at maximum force, bend test, re-bend test of all the tested samples of grade Fe500 and Fe500D TMT bars comply with minimum requirement specified in product

standard NS-191. Among the tested samples 3 (2.45 %) of Fe500 grade not comply with the minimum NS standards for bond value of their respective bar size, and grade. These samples were coded with AMB_10 mm, SR_12 mm and PKS_16 mm.

The statistical analysis of test results were examined to find variability in mechanical properties among the tested samples from different rolling mills are as follows:

- The COV for average yield strength were obtained 4.65 and standard deviation 25.80 MPa. The COV for average tensile strength were calculated 4.25 and standard deviation were 28.18 MPa.
- The COV of the percentage elongation were found 8.21 and standard deviation 1.18%. The value of COV were found 2.50 and standard deviation value were calculated 0.030 for UTS/YS ratio of Fe500.
- The COV for mass per meter run of Fe500 TMT bars were found 0.648 to 2.518 and for bond value the COV value were found 15.46 to 27.48.
- The COV for yield strength were found 4.41 and standard deviation 24.91 MPa for Fe500D. The COV for average tensile strength were calculated 3.91 and standard deviation were 26.48 MPa.
- The COV for percentage elongation were found 6.79 and standard deviation 1.49%. The value of COV for average UTS/YS ratio were found 2.057 and standard deviation value were calculated 0.025 for Fe500D.
- The COV for total elongation at maximum force were calculated 21.71 and standard deviation 1.8% for total elongation at maximum force. The COV for mass per meter run of Fe500D TMT bars were found 0.273 to 2.366 and for bond value the COV value were found 6.049 to 27.362.

5.2 Recommendations

Following recommendations has been made from the study:

- From the mechanical test results of TMT bars any brand can be used since all the rolling mills comply with specification of product standard.
- Deformed bar of Fe500D grade has higher average value for yield stress, tensile stress and percentage elongation than Fe500.
- Average UTS/YS ratio for both grade were found above 1.15 and average percentage elongation for both grade were found 22.0% which indicates the suitability of TMT bar for reinforced structures.

5.2 Further research work

Further research might be incorporated with chemical analysis of the deformed bars. The relationship between mechanical test results and chemical analysis of the tested samples can be established. The test results of the batch production from different mills of different heat can be collected and compared with independent test results data.

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ANNEX I: MECHANICAL TEST RESULTS Fe500 TMT BARS

Mill ID	Nominal size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm
JS_S1_8	8	0.395	31.22	620.4	36.9	733.3	670.0	1.182	25.0	2.89	0.96
JS_S2_8	8	0.388	26.889	544.5	33.3	674.4	588.1	1.238	17.5	2.89	0.96
JS_S3_8	8	0.399	31.22	613.9	37.6	739.4	663.0	1.204	25.0	2.89	0.96
JS_S1_10	10	0.597	47.778	628.6	54.6	718.3	678.8	1.143	26.0	2.33	1.2
JS_S2_10	10	0.621	45.778	578.4	54.4	687.3	624.7	1.188	20.0	2.33	1.2
JS_S3_10	10	0.615	44.4	566.5	50.7	646.9	611.8	1.142	22.0	2.33	1.2
JS_S1_12	12	0.922	62	528.1	73.7	627.7	570.3	1.189	25.0	3.65	1.8
JS_S2_12	12	0.876	68.667	615.5	78.6	704.5	664.7	1.145	20.0	3.65	1.8
JS_S3_12	12	0.885	61.33	544.1	73.1	648.5	587.7	1.192	25.0	3.65	1.8
JS_S1_16	16	1.521	112.889	582.8	131.1	676.8	629.4	1.161	25.0	4.12	2.4
JS_S2_16	16	1.565	108	541.7	129.9	651.6	585.1	1.203	23.8	4.12	2.4
JS_S3_16	16	1.568	110.667	554.0	128.4	642.8	598.4	1.160	22.5	4.12	2.4
JS_S1_20	20	2.456	185.556	593.0	222.3	710.5	640.5	1.198	19.0	4.73	3.4
JS_S2_20	20	2.441	176.667	568.0	211.1	678.8	613.5	1.195	25.0	4.73	3.4
JS_S3_20	20	2.422	160	518.5	191.9	621.9	560.0	1.199	24.0	4.73	3.4
JS_S1_25	25	3.834	254.445	520.9	311.1	636.9	562.6	1.223	25.0	5.51	4.25
JS_S2_25	25	3.792	247.778	513.0	309.5	640.8	554.0	1.249	25.0	5.51	4.25
JS_S3_25	25	3.797	253.333	523.7	310.5	641.9	565.6	1.226	24.2	5.51	4.25
JS_S1_28	28	4.668	327.778	551.2	402.4	676.7	595.3	1.228	20.0	5.69	4.76

Mill ID	Nominal size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm
JS_S2_28	28	4.734	311.11	515.8	366.6	607.8	557.1	1.178	17.9	5.69	4.76
JS_S3_28	28	4.703	311.11	519.3	378.4	631.7	560.9	1.216	21.4	5.69	4.76
JS_S1_32	32	6.193	417.778	529.5	512.6	649.7	571.9	1.227	21.9	6.04	5.44
JS_S2_32	32	6.169	417.778	531.6	503.4	640.6	574.1	1.205	21.3	6.04	5.44
JS_S3_32	32	6.170	408.889	520.2	513	652.7	561.9	1.255	21.9	6.04	5.44
KS_S1_8	8	0.406	28.668	554.3	34.9	674.8	598.6	1.217	25.0	1.25	0.96
KS_S2_8	8	0.397	29.33	580.3	35.7	706.3	626.7	1.217	27.5	1.25	0.96
KS_S3_8	8	0.404	32.44	630.1	38.7	751.7	680.5	1.193	22.5	1.25	0.96
KS_S1_10	10	0.595	40.889	539.3	52.6	693.8	582.5	1.286	20.0	2.05	1.2
KS_S2_10	10	0.604	42.22	548.7	51.4	668.0	592.6	1.217	18.0	2.05	1.2
KS_S3_10	10	0.584	41.22	554.0	49.7	668.0	598.4	1.206	24.0	2.05	1.2
KS_S1_12	12	0.867	62.889	569.3	76.3	690.6	614.8	1.213	16.7	2.61	1.8
KS_S2_12	12	0.883	64.22	570.9	76.3	678.3	616.6	1.188	20.0	2.61	1.8
KS_S3_12	12	0.855	63.11	579.4	74.5	684.0	625.8	1.180	25.0	2.61	1.8
KS_S1_16	16	1.543	107.11	545.0	128.1	651.8	588.6	1.196	21.3	4.30	2.4
KS_S2_16	16	1.565	111.556	559.7	133.2	668.3	604.5	1.194	23.8	4.30	2.4
KS_S3_16	16	1.550	116	587.6	133.7	677.3	634.6	1.153	18.8	4.30	2.4
KS_S1_20	20	2.415	170	552.5	203.6	661.7	596.7	1.198	22.0	5.14	3.4
KS_S2_20	20	2.469	165.778	527.0	196.2	623.7	569.1	1.184	25.0	5.14	3.4
KS_S3_20	20	2.436	173.11	557.7	201.3	648.6	602.4	1.163	24.0	5.14	3.4
KS_S1_25	25	3.894	271.11	546.5	328.3	661.8	590.2	1.211	21.7	5.03	4.25

Mill ID	Nominal size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm
KS_S2_25	25	3.883	290	586.3	340.8	689.0	633.2	1.175	23.3	5.03	4.25
KS_S3_25	25	3.813	255.556	526.2	311.3	640.9	568.2	1.218	20.8	5.03	4.25
KS_S1_28	28	4.975	343.33	541.7	414.5	654.0	585.1	1.207	22.1	4.95	4.76
KS_S2_28	28	4.765	380	626.0	442.5	728.9	676.1	1.164	18.6	4.95	4.76
KS_S3_28	28	4.780	317.778	521.8	403.3	662.3	563.6	1.269	22.9	4.95	4.76
KS_S1_32	32	6.195	404.445	512.5	493.9	625.9	553.5	1.221	18.8	7.29	5.44
KS_S2_32	32	6.156	415.556	529.9	506	645.3	572.3	1.218	18.8	7.29	5.44
KS_S3_32	32	6.195	405.556	513.9	493.9	625.9	555.0	1.218	18.8	7.29	5.44
PKS_S1_8	8	0.381	27.22	560.8	34.1	702.6	605.7	1.253	25.0	1.54	0.96
PKS_S2_8	8	0.399	31.22	613.9	37.6	739.4	663.0	1.204	25.0	1.54	0.96
PKS_S3_8	8	0.386	25.8	524.6	30.15	613.0	566.5	1.169	25.0	1.54	0.96
PKS_S1_10	10	0.610	44.667	575.0	53.1	683.6	621.0	1.189	28.0	1.98	1.2
PKS_S2_10	10	0.615	44.667	569.9	50.7	646.9	615.5	1.135	22.0	1.98	1.2
PKS_S3_10	10	0.593	43.9	581.4	51.4	680.7	627.9	1.171	14.0	1.98	1.2
PKS_S1_12	12	0.898	66.889	585.0	78.4	685.7	631.8	1.172	21.7	1.88	1.8
PKS_S2_12	12	0.885	61.33	544.1	73.1	648.5	587.7	1.192	25.0	1.88	1.8
PKS_S3_12	12	0.884	60.22	534.8	74.8	664.3	577.6	1.242	20.0	1.88	1.8
PKS_S1_16	16	1.528	107.111	550.2	126.6	650.4	594.3	1.182	22.5	1.95	2.4
PKS_S2_16	16	1.568	110.667	554.0	128.4	642.8	598.4	1.160	22.5	1.95	2.4
PKS_S3_16	16	1.588	112	553.7	137	677.3	598.0	1.223	17.5	1.95	2.4
PKS_S1_20	20	2.471	174.44	554.1	206.8	656.9	598.4	1.186	20.0	4.63	3.4

Mill ID	Nominal size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm
PKS_S2_20	20	2.422	160	518.5	191.9	621.9	560.0	1.199	24.0	4.63	3.4
PKS_S3_20	20	2.454	173	553.4	212	678.1	597.7	1.225	20.0	4.63	3.4
PKS_S1_25	25	3.876	257.778	522.1	310.9	629.7	563.9	1.206	25.0	4.86	4.25
PKS_S2_25	25	3.797	252.22	521.4	310.5	641.9	563.1	1.231	24.2	4.86	4.25
PKS_S3_25	25	3.735	243	510.7	309.5	650.4	551.5	1.274	17.5	4.86	4.25
PKS_S1_28	28	4.713	338.889	564.5	404.1	673.1	609.7	1.192	17.1	4.81	4.76
PKS_S2_28	28	4.703	311.11	519.3	378.4	631.7	560.9	1.216	23.6	4.81	4.76
PKS_S3_28	28	4.786	393	644.6	441	723.3	696.2	1.122	17.9	4.81	4.76
PKS_S1_32	32	6.216	415.556	524.8	515.4	650.9	566.8	1.240	22.5	5.55	5.44
PKS_S2_32	32	6.201	402.22	509.2	513	649.4	549.9	1.275	21.9	5.55	5.44
PKS_S3_32	32	6.290	413.33	515.8	514.3	641.8	557.1	1.244	22.5	5.55	5.44
HL_S1_8	8	0.403	29.1	566.4	36.1	702.6	611.7	1.241	25.0	1.53	0.96
HL_S2_8	8	0.388	26.889	544.5	33.3	674.4	588.1	1.238	17.5	1.53	0.96
HL_S3_8	8	0.395	31.22	620.4	36.9	733.3	670.0	1.182	25.0	1.53	0.96
HL_S1_10	10	0.584	46.22	621.4	52.6	707.2	671.1	1.138	18.0	2.19	1.2
HL_S2_10	10	0.621	45.556	575.6	54.4	687.3	621.6	1.194	20.0	2.19	1.2
HL_S3_10	10	0.597	46.889	616.9	54.6	718.3	666.2	1.164	26.0	2.19	1.2
HL_S1_12	12	0.858	58.667	536.5	69	631.0	579.5	1.176	21.7	3.18	1.8
HL_S2_12	12	0.876	68.667	615.5	78.6	704.5	664.7	1.145	20.0	3.18	1.8
HL_S3_12	12	0.922	62	528.1	73.7	627.7	570.3	1.189	26.7	3.18	1.8
HL_S1_16	16	1.574	110.22	549.6	132	658.2	593.6	1.198	20.0	4.73	2.4

Mill ID	Nominal size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm
HL_S2_16	16	1.565	108	541.7	129.9	651.6	585.1	1.203	23.8	4.73	2.4
HL_S3_16	16	1.521	112	578.2	131.1	676.8	624.4	1.171	25.0	4.73	2.4
HL_S1_20	20	2.474	177.778	564.2	216.7	687.7	609.3	1.219	19.0	4.45	3.4
HL_S2_20	20	2.441	176.667	568.0	211.1	678.8	613.5	1.195	25.0	4.45	3.4
HL_S3_20	20	2.456	186.667	596.6	222.3	710.5	644.3	1.191	19.0	4.45	3.4
HL_S1_25	25	3.941	244.445	486.9	305.3	608.1	545.0	1.249	25.0	5.22	4.25
HL_S2_25	25	3.792	247.778	513.0	309.5	640.8	554.0	1.249	25.0	5.22	4.25
HL_S3_25	25	3.834	254.44	520.9	311.1	636.9	562.6	1.223	25.0	5.22	4.25
HL_S1_28	28	4.743	308.889	511.2	378.4	626.3	552.1	1.225	20.0	5.99	4.76
HL_S2_28	28	4.734	302.22	501.1	366.6	607.8	545.0	1.213	17.9	5.99	4.76
HL_S3_28	28	4.668	327.778	551.2	402.4	676.7	595.3	1.228	20.0	5.99	4.76
HL_S1_32	32	6.255	428.889	538.3	522.7	656.0	581.4	1.219	20.0	5.53	5.44
HL_S2_32	32	6.169	417.778	531.6	503.4	640.6	574.1	1.205	21.3	5.53	5.44
HL_S3_32	32	6.193	417.778	529.5	512.6	649.7	571.9	1.227	21.9	5.53	5.44
HMA_S1_8	8	0.408	30.22	581.3	36.4	700.1	627.8	1.205	17.5	1.48	0.96
HMA_S2_8	8	0.406	28.667	554.3	34.9	674.8	598.6	1.217	25.0	1.48	0.96
HMA_S3_8	8	0.408	30.33	583.4	36.4	700.1	630.1	1.200	25.0	1.48	0.96
HMA_S1_10	10	0.610	46.667	600.8	56	721.0	648.9	1.200	24.0	1.36	1.2
HMA_S2_10	10	0.595	40.889	539.3	52.6	693.8	582.5	1.286	20.0	1.36	1.2
HMA_S3_10	10	0.606	39.22	508.3	48.3	626.0	549.0	1.232	20.0	1.36	1.2
HMA_S1_12	12	0.879	65.33	583.3	76	678.6	630.0	1.163	25.0	2.68	1.8

Mill ID	Nominal size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm
HMA_S2_12	12	0.867	62.889	569.3	76.3	690.6	614.8	1.213	16.7	2.68	1.8
HMA_S3_12	12	0.866	55.33	501.3	63.3	573.5	545.0	1.144	25.0	2.68	1.8
HMA_S1_16	16	1.555	112	565.6	134.5	679.2	610.8	1.201	22.5	3.17	2.4
HMA_S2_16	16	1.543	107.11	545.0	128.1	651.8	588.6	1.196	21.3	3.17	2.4
HMA_S3_16	16	1.537	99.556	508.6	119	607.9	549.3	1.195	25.0	3.17	2.4
HMA_S1_20	20	2.438	170	547.3	203	653.5	591.1	1.194	21.0	3.67	3.4
HMA_S2_20	20	2.415	170	552.5	203.6	661.7	596.7	1.198	22.0	3.67	3.4
HMA_S3_20	20	2.458	172.22	550.1	205.3	655.7	594.1	1.192	22.0	3.67	3.4
HMA_S1_25	25	3.809	277.778	572.4	337.7	695.9	618.2	1.216	23.3	4.25	4.25
HMA_S2_25	25	3.894	271.11	546.5	328.3	661.8	590.2	1.211	21.7	4.25	4.25
HMA_S3_25	25	3.762	285.556	595.8	338.3	705.8	643.4	1.185	22.5	4.25	4.25
HMA_S1_28	28	4.738	343.33	568.9	409	677.7	614.4	1.191	21.4	6.11	4.76
HMA_S2_28	28	4.975	341.11	538.2	414.5	654.0	581.3	1.215	22.1	6.11	4.76
HMA_S3_28	28	4.738	343.33	568.9	409	677.7	614.4	1.191	21.4	6.11	4.76
HMA_S1_32	32	6.294	444.445	554.3	531.1	662.4	598.6	1.195	21.9	6.20	5.44
HMA_S2_32	32	6.195	404.445	512.5	493.9	625.9	553.5	1.221	18.8	6.20	5.44
HMA_S3_32	32	6.150	435.556	555.9	535	682.8	600.4	1.228	22.5	6.20	5.44
LXM_S1_8	8	0.410	28	536.7	33.8	647.9	579.6	1.207	27.5	1.86	0.96
LXM_S2_8	8	0.393	31.778	634.0	40.4	806.1	684.8	1.271	25.0	1.86	0.96
LXM_S3_8	8	0.409	28	537.3	33.9	650.5	580.3	1.211	22.5	1.86	0.96
LXM_S1_10	10	0.602	41.556	541.5	51.2	667.2	584.8	1.232	20.0	2.09	1.2

Mill ID	Nominal size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm
LXM_S2_10	10	0.626	40.33	506.0	48.8	612.3	546.5	1.210	24.0	2.09	1.2
LXM_S3_10	10	0.606	42.22	546.5	49.8	644.6	590.2	1.180	18.0	2.09	1.2
LXM_S1_12	12	0.873	68.667	617.2	72.2	649.0	666.6	1.051	21.7	2.98	1.8
LXM_S2_12	12	0.883	71.778	638.4	97.1	863.6	689.4	1.353	16.7	2.98	1.8
LXM_S3_12	12	0.873	62	557.3	72.2	649.0	601.9	1.165	16.7	2.98	1.8
LXM_S1_16	16	1.559	112.889	568.5	132.8	668.8	614.0	1.176	20.0	4.08	2.4
LXM_S2_16	16	1.624	102.22	494.0	126.7	612.3	545.0	1.239	22.5	4.08	2.4
LXM_S3_16	16	1.527	100	514.0	122.6	630.1	555.1	1.226	22.5	4.08	2.4
LXM_S1_20	20	2.432	175.556	566.7	210.2	678.5	612.0	1.197	20.0	4.61	3.4
LXM_S2_20	20	2.409	175.556	572.1	214.2	698.1	617.9	1.220	17.0	4.61	3.4
LXM_S3_20	20	2.401	160.44	524.6	195.7	639.9	566.6	1.220	22.0	4.61	3.4
LXM_S1_25	25	3.755	262.22	548.1	310.3	648.6	592.0	1.183	22.5	6.12	4.25
LXM_S2_25	25	3.712	240	507.6	283.1	598.7	548.2	1.180	23.3	6.12	4.25
LXM_S3_25	25	3.781	250	519.1	307.4	638.2	560.6	1.230	20.0	6.12	4.25
LXM_S1_28	28	4.749	311.1	514.2	394.7	652.4	555.4	1.269	15.0	7.44	4.76
LXM_S2_28	28	4.880	334.445	537.9	410.1	659.6	581.0	1.226	21.4	7.44	4.76
LXM_S3_28	28	4.749	310	512.4	394.7	652.4	553.4	1.273	17.1	7.44	4.76
LXM_S1_32	32	6.405	422.22	517.5	523.5	641.6	558.9	1.240	20.6	7.99	5.44
LXM_S2_32	32	6.049	388.889	504.7	491.3	637.6	545.0	1.263	18.8	7.99	5.44
LXM_S3_32	32	6.405	420	514.8	523.5	641.6	555.9	1.246	20.0	7.99	5.44
AMB_S1_8	8	0.399	29.95	589.0	34.85	685.3	636.1	1.164	25.0	1.06	0.96

Mill ID	Nominal size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm
AMB_S2_8	8	0.395	29.25	581.7	33.75	671.2	628.3	1.154	25.0	1.06	0.96
AMB_S3_8	8	0.391	29.6	594.5	34.85	700.0	642.1	1.177	18.8	1.06	0.96
AMB_S1_10	10	0.604	45.5	591.6	53.75	698.9	639.0	1.181	30.0	1.22	1.2
AMB_S2_10	10	0.597	42	552.6	48.5	638.1	596.8	1.155	24.0	1.22	1.2
AMB_S3_10	10	0.591	43.5	577.7	48.75	647.5	624.0	1.121	20.0	1.22	1.2
AMB_S1_12	12	0.856	65	595.8	76.5	701.2	643.4	1.177	25.0	1.80	1.8
AMB_S2_12	12	0.852	61.75	568.9	76.25	702.5	614.4	1.235	28.3	1.80	1.8
AMB_S3_12	12	0.885	59	523.4	72	638.7	565.3	1.220	21.7	1.80	1.8
AMB_S1_16	16	1.537	105.25	537.7	126.25	645.0	580.7	1.200	21.3	2.51	2.4
AMB_S2_16	16	1.549	111.25	563.8	130	658.8	608.9	1.169	25.0	2.51	2.4
AMB_S3_16	16	1.547	107.5	545.5	131	664.7	589.1	1.219	22.5	2.51	2.4
AMB_S1_20	20	2.416	162.5	527.9	216	701.7	570.2	1.329	25.0	3.42	3.4
AMB_S2_20	20	2.375	170	561.9	205	677.6	606.8	1.206	25.0	3.42	3.4
AMB_S3_20	20	2.436	169.5	546.1	199.5	642.8	589.8	1.177	28.0	3.42	3.4
AMB_S1_25	25	3.846	268	547.0	331.5	676.6	590.7	1.237	25.0	4.80	4.25
AMB_S2_25	25	3.859	262.5	534.0	320	650.9	576.7	1.219	25.0	4.80	4.25
AMB_S3_25	25	3.745	255	534.5	305.5	640.4	577.3	1.198	20.8	4.80	4.25
GNK_S1_8	8	0.382	28.11	578.1	34.1	701.3	624.4	1.213	20.0	1.23	0.96
GNK_S2_8	8	0.373	30.33	638.7	35.778	753.5	689.8	1.180	25.0	1.23	0.96
GNK_S3_8	8	0.382	28.11	578.1	33.9	697.2	624.4	1.206	22.5	1.23	0.96
GNK_S1_10	10	0.586	46.44	621.9	54.4	728.5	671.7	1.171	22.0	2.02	1.2

Mill ID	Nominal size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, Ar, mm	Required Bond, mm
GNK_S2_10	10	0.601	44.89	586.3	53.1	693.6	633.2	1.183	24.0	2.02	1.2
GNK_S3_10	10	0.594	38.778	512.8	49.8	658.5	553.8	1.284	18.0	2.02	1.2
GNK_S1_12	12	0.875	70.667	634.0	82.9	743.7	684.7	1.173	25.0	3.13	1.8
GNK_S2_12	12	0.869	59.556	538.2	72.4	654.2	581.2	1.216	25.0	3.13	1.8
GNK_S3_12	12	0.875	70.889	636.0	72.2	647.7	686.9	1.018	25.0	3.13	1.8
GNK_S1_16	16	1.560	114.667	577.0	134.6	677.3	623.2	1.174	23.8	5.48	2.4
GNK_S2_16	16	1.549	116	588.0	138.5	702.0	635.0	1.194	23.8	5.48	2.4
GNK_S3_16	16	1.509	99.556	518.0	122.6	637.9	559.4	1.231	22.5	5.48	2.4
GNK_S1_20	20	2.436	178.889	576.4	217.4	700.5	622.5	1.215	19.0	6.49	3.4
GNK_S2_20	20	2.439	190	611.6	213.8	688.2	660.5	1.125	22.0	6.49	3.4
GNK_S3_20	20	2.439	191.11	615.2	195.7	630.0	664.4	1.024	22.0	6.49	3.4
GNK_S1_25	25	3.855	284.445	579.2	340.1	692.5	625.5	1.196	20.0	5.19	4.25
GNK_S2_25	25	3.802	294.445	607.9	350.5	723.6	656.5	1.190	16.7	5.19	4.25
GNK_S3_25	25	3.965	294.445	582.9	307.4	608.6	629.6	1.044	20.0	5.19	4.25
FRO_S1_8	8	0.414	31.5	597.0	35.1	665.3	644.8	1.114	20.0	1.41	0.96
FRO_S2_8	8	0.390	29.9	602.0	35.7	718.8	650.1	1.194	20.0	1.41	0.96
FRO_S3_8	8	0.406	29.65	573.5	35.5	686.7	619.4	1.197	25.0	1.41	0.96
FRO_S1_10	10	0.612	48	616.0	55.75	715.5	665.3	1.161	24.0	2.15	1.2
FRO_S2_10	10	0.639	40.9	502.6	48.3	593.5	545.0	1.181	30.0	2.15	1.2
FRO_S3_10	10	0.625	44.65	560.6	52.6	660.5	605.5	1.178	22.0	2.15	1.2
FRO_S1_12	12	0.895	68.5	600.6	80.75	708.0	648.6	1.179	13.3	2.45	1.8

Mill ID	Nominal size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm
FRO_S2_12	12	0.883	60.5	537.8	71.75	637.8	580.8	1.186	16.7	2.45	1.8
FRO_S3_12	12	0.883	66	587.0	79.25	704.8	633.9	1.201	23.3	2.45	1.8
FRO_S1_16	16	1.555	110	555.2	135	681.3	599.6	1.227	21.3	4.03	2.4
FRO_S2_16	16	1.583	108	535.6	131.25	650.9	578.4	1.215	22.5	4.03	2.4
FRO_S3_16	16	1.536	110.5	564.7	134	684.8	609.9	1.213	25.0	4.03	2.4
FRO_S1_20	20	2.374	157.5	520.9	197	651.5	562.6	1.251	24.0	5.58	3.4
FRO_S2_20	20	2.485	160.5	507.0	202.5	639.6	547.5	1.262	25.0	5.58	3.4
FRO_S3_20	20	2.374	160	529.2	196	648.2	571.5	1.225	23.0	5.58	3.4
FRO_S1_25	25	3.706	240.5	509.4	294.5	623.8	550.2	1.225	25.8	6.34	4.25
FRO_S2_25	25	3.758	274	572.3	326.5	682.0	618.1	1.192	20.0	6.34	4.25
FRO_S3_25	25	3.782	286	593.6	341	707.8	641.1	1.192	20.8	6.34	4.25
FRO_S1_28	28	4.640	318.5	538.9	395	668.3	582.0	1.240	21.4	6.82	4.76
FRO_S2_28	28	4.768	326.5	537.6	402.5	662.7	580.6	1.233	22.9	6.82	4.76
FRO_S3_28	28	4.640	311	526.2	386	653.1	568.3	1.241	21.4	6.82	4.76
JGSKT_S1_8	8	0.396	26.44	524.4	33	654.6	566.4	1.248	20.0	2.00	0.96
JGSKT_S2_8	8	0.385	27.9	569.3	32.95	672.3	614.8	1.181	20.0	2.00	0.96
JGSKT_S3_8	8	0.387	26.5	537.0	31	628.1	579.9	1.170	25.0	2.00	0.96
JGSKT_S1_10	10	0.588	40.889	546.0	51.9	693.1	589.7	1.269	22.0	2.23	1.2
JGSKT_S2_10	10	0.599	43.7	572.8	50.55	662.5	618.6	1.157	26.0	2.23	1.2
JGSKT_S3_10	10	0.592	42.75	567.1	49.1	651.4	612.5	1.149	20.0	2.23	1.2
JGSKT_S1_12	12	0.876	68.667	615.5	78.6	704.5	664.7	1.145	20.0	2.38	1.8

Mill ID	Nominal size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, Ar, mm	Required Bond, mm
JGSKT_S2_12	12	0.869	61.75	558.1	71.5	646.3	602.8	1.158	26.7	2.38	1.8
JGSKT_S3_12	12	0.880	66.25	591.1	77.25	689.2	638.4	1.166	20.0	2.38	1.8
JGSKT_S1_16	16	1.572	113.778	568.0	140.2	699.9	613.4	1.232	18.8	3.54	2.4
JGSKT_S2_16	16	1.555	108.5	547.7	139	701.7	591.6	1.281	18.8	3.54	2.4
JGSKT_S3_16	16	1.567	112	561.0	137.5	688.7	605.9	1.228	18.8	3.54	2.4
JGSKT_S1_20	20	2.415	162.22	527.4	196.4	638.5	569.5	1.211	20.0	5.04	3.4
JGSKT_S2_20	20	2.429	162.5	525.2	200	646.4	567.2	1.231	22.0	5.04	3.4
JGSKT_S3_20	20	2.478	177.5	562.4	211	668.5	607.4	1.189	20.0	5.04	3.4
JGSKT_S1_25	25	3.701	274.445	582.1	334.7	709.9	628.7	1.220	24.2	4.30	4.25
JGSKT_S2_25	25	3.897	276	556.0	327	658.7	600.5	1.185	22.5	4.30	4.25
JGSKT_S3_25	25	3.794	270	558.7	328.5	679.7	603.4	1.217	20.8	4.30	4.25
HLS_S1_8	8	0.380	28.44	587.5	34.1	704.4	634.5	1.199	17.5	2.26	0.96
HLS_S2_8	8	0.376	29.33	613.0	36.5	762.8	662.0	1.244	25.0	2.26	0.96
HLS_S3_8	8	0.410	27.33	522.7	33.9	648.4	564.5	1.240	22.5	2.26	0.96
HLS_S1_10	10	0.588	40.667	543.1	51.9	693.1	586.5	1.276	20.0	1.95	1.2
HLS_S2_10	10	0.604	42.889	557.5	53.3	692.8	602.0	1.243	20.0	1.95	1.2
HLS_S3_10	10	0.606	40.556	525.0	49.8	644.6	567.0	1.228	22.0	1.95	1.2
HLS_S1_12	12	0.875	58.4	524.1	70.1	629.0	566.0	1.200	16.7	3.57	1.8
HLS_S2_12	12	0.868	59.11	534.7	71.8	649.5	577.5	1.215	20.0	3.57	1.8
HLS_S3_12	12	0.873	60.22	541.3	72.2	649.0	584.6	1.199	20.0	3.57	1.8
HLS_S1_16	16	1.543	98.667	502.1	124.4	633.0	545.0	1.261	22.5	4.33	2.4

Mill ID	Nominal size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm
HLS_S2_16	16	1.572	107.556	537.0	123.2	615.1	579.9	1.145	25.0	4.33	2.4
HLS_S3_16	16	1.527	100	514.0	122.6	630.1	555.1	1.226	22.5	4.33	2.4
HLS_S1_20	20	2.486	162.667	513.7	193.5	611.0	554.7	1.190	17.0	5.05	3.4
HLS_S2_20	20	2.461	165.33	527.5	196.5	626.9	569.7	1.189	26.0	5.05	3.4
HLS_S3_20	20	2.401	160.44	524.6	195.7	639.9	566.6	1.220	22.0	5.05	3.4
HLS_S1_25	25	3.844	247.778	505.9	290.9	594.0	546.4	1.174	29.2	4.46	4.25
HLS_S2_25	25	3.850	261.11	532.5	315.5	643.4	575.0	1.208	20.0	4.46	4.25
HLS_S3_25	25	3.781	250	519.1	307.4	638.2	560.6	1.230	20.0	4.46	4.25
SLMR_S1_8	8	0.387	27.1	549.3	32.2	652.7	593.2	1.188	20.0	2.28	0.96
SLMR_S2_8	8	0.390	32.75	659.5	35.5	714.9	712.3	1.084	20.0	2.28	0.96
SLMR_S3_8	8	0.385	28.5	580.6	33.4	680.4	627.1	1.172	22.5	2.28	0.96
SLMR_S1_10	10	0.598	42	551.1	49.4	648.1	595.1	1.176	20.0	2.59	1.2
SLMR_S2_10	10	0.582	52	701.0	57.5	775.1	757.0	1.106	20.0	2.59	1.2
SLMR_S3_10	10	0.596	47.75	629.1	53.4	703.6	679.5	1.118	20.0	2.59	1.2
SLMR_S1_12	12	0.875	67.25	603.6	76.5	686.6	651.9	1.138	16.7	3.67	1.8
SLMR_S2_12	12	0.881	56.25	501.4	68.75	612.8	545.0	1.222	20.0	3.67	1.8
SLMR_S3_12	12	0.867	56.25	509.3	62.75	568.2	550.1	1.116	21.7	3.67	1.8
SLMR_S1_16	16	1.559	111.25	560.3	133.5	672.4	605.1	1.200	20.0	5.23	2.4
SLMR_S2_16	16	1.546	104.5	530.7	127.5	647.6	573.2	1.220	21.3	5.23	2.4
SLMR_S3_16	16	1.519	105.25	543.8	116.75	603.2	587.3	1.109	22.5	5.23	2.4
SLMR_S1_20	20	2.419	188	610.0	216	700.8	658.8	1.149	17.0	5.73	3.4

Mill ID	Nominal size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm
SLMR_S2_20	20	2.457	172	549.5	212.5	678.9	593.5	1.235	19.0	5.73	3.4
SLMR_S3_20	20	2.434	162.5	524.0	201	648.1	565.9	1.237	20.0	5.73	3.4
SLMR_S1_25	25	3.920	277.5	555.7	323.5	647.8	600.1	1.166	19.2	7.72	4.25
SLMR_S2_25	25	3.814	282.5	581.4	342.5	704.9	627.9	1.212	22.5	7.72	4.25
SLMR_S3_25	25	3.915	276	553.4	322.5	646.6	597.6	1.168	20.0	7.72	4.25
SKH_S1_8	8	0.408	32.75	629.8	39.25	754.8	680.2	1.198	20.0	1.74	0.96
SKH_S2_8	8	0.393	30.25	603.9	35.5	708.7	652.2	1.174	25.0	1.74	0.96
SKH_S3_8	8	0.433	31.5	571.2	37.5	680.0	616.9	1.190	25.0	1.74	0.96
SKH_S1_10	10	0.640	41.5	508.8	51.2	627.7	549.5	1.234	20.0	2.00	1.2
SKH_S2_10	10	0.601	45.35	592.5	51.4	671.6	639.9	1.133	26.0	2.00	1.2
SKH_S3_10	10	0.641	41.75	511.0	51.2	626.7	551.9	1.226	20.0	2.00	1.2
SKH_S1_12	12	0.890	57.5	507.1	63	555.6	547.6	1.096	23.3	2.58	1.8
SKH_S2_12	12	0.868	62.25	562.8	71.75	648.6	607.8	1.153	21.7	2.58	1.8
SKH_S3_12	12	0.893	58	509.9	62.5	549.5	550.7	1.078	25.0	2.58	1.8
SKH_S1_16	16	1.510	103.75	539.4	113.25	588.8	582.5	1.092	18.8	3.56	2.4
SKH_S2_16	16	1.545	111.25	565.1	125.75	638.7	610.3	1.130	26.3	3.56	2.4
SKH_S3_16	16	1.555	101.25	511.3	113	570.6	552.2	1.116	21.3	3.56	2.4
SKH_S1_20	20	2.508	203.5	636.9	233.5	730.8	687.8	1.147	18.0	4.32	3.4
SKH_S2_20	20	2.433	176	568.0	209.5	676.1	613.4	1.190	19.0	4.32	3.4
SKH_S3_20	20	2.504	188	589.4	220	689.7	636.6	1.170	25.0	4.32	3.4
SKH_S1_25	25	3.784	253.5	525.9	315.5	654.5	567.9	1.245	22.5	4.76	4.25

Mill ID	Nominal size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm
SKH_S2_25	25	3.748	260	544.5	320	670.2	588.1	1.231	20.0	4.76	4.25
SKH_S3_25	25	3.713	242.5	512.6	291.5	616.2	553.6	1.202	16.7	4.76	4.25
ASK_S1_8	8	0.393	29.889	596.8	37.3	744.8	644.5	1.248	25.0	2.00	0.96
ASK_S2_8	8	0.389	31.667	639.7	37.2	751.4	690.8	1.175	22.5	2.00	0.96
ASK_S3_8	8	0.411	30.444	581.0	36.4	694.7	627.5	1.196	22.5	2.00	0.96
ASK_S1_10	10	0.611	44.22	567.9	57.2	734.5	613.3	1.294	20.0	2.10	1.2
ASK_S2_10	10	0.601	42.22	551.6	52.6	687.2	595.7	1.246	24.0	2.10	1.2
ASK_S3_10	10	0.598	40.11	526.2	46.1	604.8	568.3	1.149	22.0	2.10	1.2
ASK_S1_12	12	0.869	66.44	599.9	79.7	719.6	647.9	1.200	23.3	2.01	1.8
ASK_S2_12	12	0.864	61.556	559.1	72.2	655.8	603.8	1.173	23.3	2.01	1.8
ASK_S3_12	12	0.903	60.667	527.2	73.5	638.7	569.4	1.212	21.7	2.01	1.8
ASK_S1_16	16	1.556	113.33	571.7	139.7	704.7	617.4	1.233	20.0	4.15	2.4
ASK_S2_16	16	1.537	110.667	565.2	133	679.3	610.4	1.202	20.0	4.15	2.4
ASK_S3_16	16	1.603	106.667	522.3	126.9	621.3	564.0	1.190	21.3	4.15	2.4
ASK_S1_20	20	2.441	176.667	568.1	212.9	684.6	613.5	1.205	22.0	5.66	3.4
ASK_S2_20	20	2.466	180.11	573.4	215	684.5	619.3	1.194	24.0	5.66	3.4
ASK_S3_20	20	2.506	168.889	529.1	202.6	634.7	571.4	1.200	21.0	5.66	3.4
SR_S1_8	8	0.414	29.11	552.1	37.1	703.6	596.3	1.274	25.0	1.11	0.96
SR_S2_8	8	0.415	27.75	525.1	34.25	648.1	567.1	1.234	30.0	1.11	0.96
SR_S3_8	8	0.405	31.5	610.8	38.4	744.5	659.6	1.219	20.0	1.11	0.96
SR_S1_10	10	0.614	45.33	579.7	52.8	675.2	626.1	1.165	20.0	1.24	1.2

Mill ID	Nominal size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm
SR_S2_10	10	0.626	51	639.6	57.25	717.9	690.7	1.123	24.0	1.24	1.2
SR_S3_10	10	0.609	46.25	596.6	56.75	732.1	644.4	1.227	22.0	1.24	1.2
SR_S1_12	12	0.906	61.556	533.5	75.7	656.1	576.2	1.230	18.3	2.09	1.8
SR_S2_12	12	0.881	56.75	505.9	63.25	563.8	546.3	1.115	25.0	2.09	1.8
SR_S3_12	12	0.889	58.75	519.0	63.75	563.1	560.5	1.085	20.0	2.09	1.8
SR_S1_16	16	1.572	101.33	506.1	129.1	644.8	546.6	1.274	21.3	3.00	2.4
SR_S2_16	16	1.489	101	532.5	111.25	586.5	575.1	1.101	22.5	3.00	2.4
SR_S3_16	16	1.496	101.5	532.6	111.5	585.1	575.2	1.099	22.5	3.00	2.4
SR_S1_20	20	2.476	164	519.9	198.9	630.6	561.5	1.213	23.0	3.79	3.4
SR_S2_20	20	2.563	182.5	558.9	230	704.4	603.6	1.260	21.0	3.79	3.4
SR_S3_20	20	2.539	183.5	567.4	229	708.0	612.8	1.248	17.0	3.79	3.4
EVRL_S1_8	8	0.403	30.556	594.7	34.5	671.5	642.3	1.129	25.0	1.76	0.96
EVRL_S2_8	8	0.410	27.33	522.7	33.9	648.4	564.5	1.240	22.5	1.76	0.96
EVRL_S3_8	8	0.409	28.4	545.6	34.75	667.6	589.3	1.224	22.5	1.76	0.96
EVRL_S1_10	10	0.600	43.778	572.3	53.6	700.7	618.1	1.224	26.0	1.47	1.2
EVRL_S2_10	10	0.606	40.44	523.5	49.8	644.6	565.4	1.231	24.0	1.47	1.2
EVRL_S3_10	10	0.617	42.25	537.9	51.05	650.0	581.0	1.208	22.0	1.47	1.2
EVRL_S1_12	12	0.881	64.889	577.9	75.7	674.2	624.1	1.167	25.0	1.80	1.8
EVRL_S2_12	12	0.873	60.22	541.3	72.2	649.0	584.6	1.199	26.7	1.80	1.8
EVRL_S3_12	12	0.871	62.22	560.6	75.7	682.0	605.4	1.217	23.3	1.80	1.8
EVRL_S1_16	16	1.557	107.11	540.0	126.2	636.2	583.2	1.178	21.3	2.42	2.4

Mill ID	Nominal size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm
EVRL_S2_16	16	1.527	100	514.0	122.6	630.1	555.1	1.226	22.5	2.42	2.4
EVRL_S3_16	16	1.558	103.11	519.5	127.9	644.4	561.0	1.240	20.0	2.42	2.4
EVRL_S1_20	20	2.513	163.556	511.0	198.7	620.8	551.9	1.215	23.0	3.77	3.4
EVRL_S2_20	20	2.401	160.889	526.1	195.7	639.9	568.2	1.216	22.0	3.77	3.4
EVRL_S3_20	20	2.502	167.778	526.5	203.5	638.6	568.6	1.213	23.0	3.77	3.4
NRS_S1_8	8	0.416	27.556	520.4	33.1	625.1	562.0	1.201	22.5	1.50	0.96
NRS_S2_8	8	0.411	30.44	580.9	36.4	694.7	627.4	1.196	22.5	1.50	0.96
NRS_S3_8	8	0.403	30.44	592.5	34.5	671.5	639.9	1.133	25.0	1.50	0.96
NRS_S1_10	10	0.609	42	541.0	53.4	687.8	584.3	1.271	16.0	1.80	1.2
NRS_S2_10	10	0.598	40	524.8	46.1	604.8	566.7	1.153	22.0	1.80	1.2
NRS_S3_10	10	0.600	45.33	592.6	53.6	700.7	640.0	1.182	26.0	1.80	1.2
NRS_S1_12	12	0.881	57.33	510.6	75.3	670.7	551.5	1.313	21.7	2.88	1.8
NRS_S2_12	12	0.903	60.22	523.3	73.5	638.7	565.2	1.221	21.7	2.88	1.8
NRS_S3_12	12	0.881	64.667	575.9	75.7	674.2	622.0	1.171	25.0	2.88	1.8
NRS_S1_16	16	1.571	116.44	582.0	137.1	685.2	628.5	1.177	20.0	2.38	2.4
NRS_S2_16	16	1.603	102.667	502.7	126.9	621.3	545.0	1.236	21.3	2.38	2.4
NRS_S3_16	16	1.557	107.11	540.0	126.2	636.2	583.2	1.178	21.3	2.38	2.4
NRS_S1_20	20	2.535	165.556	512.7	202.6	627.4	553.7	1.224	23.0	3.81	3.4
NRS_S2_20	20	2.506	168.889	529.1	202.6	634.7	571.4	1.200	24.0	3.81	3.4
NRS_S3_20	20	2.513	166.22	519.3	198.7	620.8	560.9	1.195	22.0	3.81	3.4
PSPT_S1_8	8	0.410	27	517.5	33.8	647.9	558.9	1.252	27.5	1.97	0.96

Mill ID	Nominal size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm
PSPT_S2_8	8	0.375	26.7	559.2	31.65	662.9	604.0	1.185	25.0	1.97	0.96
PSPT_S3_8	8	0.371	27	570.6	31.6	667.8	616.2	1.170	22.5	1.97	0.96
PSPT_S1_10	10	0.602	41.33	538.5	51.2	667.2	581.6	1.239	20.0	1.84	1.2
PSPT_S2_10	10	0.600	42.8	560.1	51.7	676.6	604.9	1.208	26.0	1.84	1.2
PSPT_S3_10	10	0.599	43.35	568.4	51.35	673.3	613.9	1.185	28.0	1.84	1.2
PSPT_S1_12	12	0.903	60.44	525.2	73.5	638.7	567.3	1.216	21.7	2.19	1.8
PSPT_S2_12	12	0.854	59.556	547.5	73.3	673.8	591.3	1.231	28.3	2.19	1.8
PSPT_S3_12	12	0.852	65.11	599.8	77.3	712.1	647.8	1.187	25.0	2.19	1.8
PSPT_S1_16	16	1.559	112.889	568.5	132.8	668.8	614.0	1.176	20.0	2.98	2.4
PSPT_S2_16	16	1.566	112.889	565.8	137.4	688.7	611.1	1.217	20.0	2.98	2.4
PSPT_S3_16	16	1.566	115.556	579.1	138.8	695.6	625.4	1.201	25.0	2.98	2.4
PSPT_S1_20	20	2.432	174.44	563.1	210.2	678.5	608.1	1.205	20.0	3.77	3.4
PSPT_S2_20	20	2.434	180	580.4	209.8	676.5	626.9	1.166	22.0	3.77	3.4
PSPT_S3_20	20	2.436	173.33	558.6	208.2	671.0	603.3	1.201	23.0	3.77	3.4
PSPT_S1_25	25	3.755	262.22	548.1	310.3	648.6	592.0	1.183	22.5	4.68	4.25
PSPT_S2_25	25	3.813	290	597.1	346.8	714.1	644.9	1.196	20.8	4.68	4.25
PSPT_S3_25	25	3.811	290	597.3	345.7	712.0	645.1	1.192	22.5	4.68	4.25
PSI_S1_8	8	0.412	26.5	505.5	31.1	593.3	546.0	1.174	27.5	12.81	0.96
PSI_S2_8	8	0.411	26.4	504.7	31.35	599.4	545.1	1.188	27.5	1.33	0.96
PSI_S3_8	8	0.405	26.2	507.7	31.6	612.3	548.3	1.206	25.0	1.33	0.96
PSI_S1_10	10	0.585	39.2	526.4	46.6	625.8	568.5	1.189	22.0	2.18	1.2

Mill ID	Nominal size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm
PSI_S2_10	10	0.585	37.5	503.1	42.1	564.8	545.0	1.123	18.0	2.18	1.2
PSI_S3_10	10	0.609	40.5	522.0	45.25	583.3	563.8	1.117	22.0	2.18	1.2
PSI_S1_12	12	0.904	65	564.3	75.5	655.5	609.5	1.162	18.3	3.04	1.8
PSI_S2_12	12	0.885	65	576.2	74.75	662.7	622.3	1.150	18.3	3.04	1.8
PSI_S3_12	12	0.870	57.75	521.2	67.75	611.4	562.9	1.173	20.0	3.04	1.8
PSI_S1_16	16	1.569	100	500.3	121.75	609.2	545.0	1.218	25.0	3.33	2.4
PSI_S2_16	16	1.548	99.5	504.5	121.75	617.3	545.0	1.224	20.0	3.33	2.4
PSI_S3_16	16	1.566	109.25	547.5	132.25	662.8	591.3	1.211	18.8	3.33	2.4
PSI_S1_20	20	2.398	162.5	531.9	181	592.4	574.4	1.114	19.0	3.58	3.4
PSI_S2_20	20	2.395	164.5	539.2	194	635.9	582.3	1.179	18.0	3.58	3.4
PSI_S3_20	20	2.384	165	543.3	195.5	643.7	586.8	1.185	25.0	3.58	3.4

ANNEX II: MECHANICAL TEST RESULTS Fe500D TMT BARS

Mill ID	Nominal Size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm	Total Elongation at Max. Force, %
RHN_S1_8	8	0.373	30.3	638.7	36.7	772.9	702.6	1.210	25.0	1.06	0.96	6.4
RHN_S2_8	8	0.388	27.5	556.2	32.75	662.3	611.8	1.191	25.0	1.06	0.96	7.8
RHN_S3_8	8	0.383	27.6	565.0	32.6	667.4	621.5	1.181	25.0	1.06	0.96	7.8
RHN_S1_10	10	0.601	44.9	586.3	53.1	693.6	645.0	1.183	30.0	2.35	1.2	11.3
RHN_S2_10	10	0.599	45.0	589.4	54	707.3	648.3	1.200	20.0	2.35	1.2	6.4
RHN_S3_10	10	0.594	41.1	543.0	50.15	662.5	597.3	1.220	20.0	2.35	1.2	5.7
RHN_S1_12	12	0.869	59.6	538.2	72.4	654.2	592.0	1.216	25.0	3.33	1.8	12.2
RHN_S2_12	12	0.855	61.1	561.0	75.4	692.2	617.1	1.234	21.7	3.33	1.8	13.7
RHN_S3_12	12	0.857	59.3	543.3	76	695.9	597.6	1.281	21.7	3.33	1.8	10.3
RHN_S1_16	16	1.549	114.7	581.2	138.5	702.0	639.4	1.208	23.8	3.56	2.4	11.1
RHN_S2_16	16	1.549	119.1	603.6	141.6	717.5	663.9	1.189	22.5	3.56	2.4	10.4
RHN_S3_16	16	1.553	120.0	606.7	144.6	731.0	667.3	1.205	22.5	3.56	2.4	10.4
RHN_S1_20	20	2.439	175.6	565.1	223.4	719.1	621.6	1.273	22.0	4.62	3.4	10.1
RHN_S2_20	20	2.423	175.6	568.8	211	683.6	625.6	1.202	21.0	4.62	3.4	7.2
RHN_S3_20	20	2.415	180.0	585.1	209.7	681.6	643.6	1.165	21.0	4.62	3.4	7.3
RHN_S1_25	25	3.802	294.4	607.9	350.5	723.6	668.7	1.190	16.7	4.78	4.25	6.2
RHN_S2_25	25	3.803	270.0	557.4	331.7	684.7	613.1	1.229	20.8	4.78	4.25	8.7
RHN_S3_25	25	3.769	271.1	564.7	339.3	706.7	621.2	1.252	20.8	4.78	4.25	7.0

Mill ID	Nominal Size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm	Total Elongation at Max. Force, %
RHN_S1_28	28	4.769	357.8	589.0	429.9	707.7	647.9	1.202	19.3	5.76	4.76	5.4
RHN_S2_28	28	4.787	334.4	548.4	414.4	679.5	603.3	1.239	20.0	5.76	4.76	7.0
RHN_S3_28	28	4.904	340.0	544.3	414.3	663.2	598.7	1.219	20.0	5.76	4.76	9.6
RHN_S1_32	32	6.252	480.0	602.7	569.7	715.4	663.0	1.187	23.8	6.58	5.44	10.4
RHN_S2_32	32	6.258	466.7	585.4	560.3	702.9	643.9	1.201	20.0	6.58	5.44	12.0
RHN_S3_32	32	6.252	480.0	602.7	569.7	715.4	663.0	1.187	20.0	6.58	5.44	9.1
KSRB_S1_8	8	0.406	28.8	556.5	33.9	655.6	612.2	1.178	22.5	1.14	0.96	5.3
KSRB_S2_8	8	0.405	27.2	527.5	31.35	608.0	580.3	1.153	25.0	1.14	0.96	5.3
KSRB_S3_8	8	0.407	27.6	532.8	31.5	608.1	586.1	1.141	25.0	1.14	0.96	6.6
KSRB_S1_10	10	0.594	38.6	509.4	45	594.6	565.0	1.167	28.0	1.78	1.2	5.6
KSRB_S2_10	10	0.606	39.5	511.3	47.55	616.3	565.0	1.205	20.0	1.78	1.2	6.7
KSRB_S3_10	10	0.606	39.9	516.8	49.3	638.5	568.4	1.236	20.0	1.78	1.2	6.0
KSRB_S1_12	12	0.860	62.4	570.3	73.9	674.9	627.3	1.184	23.3	4.49	1.8	13.0
KSRB_S2_12	12	0.876	56.7	508.0	71.7	642.8	565.0	1.265	23.3	4.49	1.8	12.0
KSRB_S3_12	12	0.911	65.3	562.9	77.2	665.2	619.2	1.182	21.7	4.49	1.8	8.1
KSRB_S1_16	16	1.527	116.0	596.3	137.1	704.7	655.9	1.182	18.8	2.80	2.4	8.7
KSRB_S2_16	16	1.547	111.6	566.2	131.5	667.4	622.8	1.179	18.8	2.80	2.4	5.3
KSRB_S3_16	16	1.579	120.0	596.7	145	721.0	656.4	1.208	21.3	2.80	2.4	6.4
KSRB_S1_20	20	2.480	190.0	601.4	220.7	698.6	661.5	1.162	19.0	5.11	3.4	5.3
KSRB_S2_20	20	2.415	167.8	545.3	204	663.0	599.8	1.216	22.0	5.11	3.4	7.3

Mill ID	Nominal Size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm	Total Elongation at Max. Force, %
KSRB_S3_20	20	2.440	174.4	561.3	204	656.4	617.4	1.169	20.0	5.11	3.4	9.3
KSRB_S1_25	25	3.813	282.2	581.0	343.3	706.7	639.1	1.216	26.7	6.00	4.25	11.5
KSRB_S2_25	25	3.873	277.8	563.1	332.1	673.2	619.4	1.196	20.8	6.00	4.25	7.0
KSRB_S3_25	25	3.810	280.0	576.8	332.4	684.8	634.5	1.187	20.8	6.00	4.25	7.8
KSRB_S1_28	28	4.767	368.9	607.5	435.8	717.7	668.3	1.181	17.9	5.15	4.76	10.4
KSRB_S2_28	28	4.748	352.2	582.3	417.8	690.7	640.6	1.186	22.9	5.15	4.76	7.5
KSRB_S3_28	28	4.767	370.0	609.3	435.8	717.7	670.3	1.178	20.0	5.15	4.76	10.4
KSRB_S1_32	32	6.141	448.9	573.8	536	685.2	631.2	1.194	22.5	7.16	5.44	9.1
KSRB_S2_32	32	6.212	437.8	553.2	534.5	675.4	608.5	1.221	20.6	7.16	5.44	9.1
KSRB_S3_32	32	6.336	424.4	525.9	519.5	643.7	578.5	1.224	20.6	7.16	5.44	9.7
FRO_S1_8	8	0.406	29.7	573.5	35.5	686.7	630.9	1.197	25.0	1.70	0.96	5.3
FRO_S2_8	8	0.390	30.9	622.6	35	705.2	684.8	1.133	20.0	1.70	0.96	5.4
FRO_S3_8	8	0.414	31.5	597.0	35.1	665.3	656.7	1.114	20.0	1.70	0.96	5.3
FRO_S1_10	10	0.625	44.7	560.6	52.6	660.5	616.7	1.178	22.0	2.34	1.2	5.7
FRO_S2_10	10	0.636	40.8	503.3	47	580.5	565.0	1.153	22.0	2.34	1.2	5.6
FRO_S3_10	10	0.612	48.0	616.0	55.75	715.5	677.6	1.161	24.0	2.34	1.2	5.7
FRO_S1_12	12	0.883	66.0	587.0	79.25	704.8	645.7	1.201	23.3	2.60	1.8	10.4
FRO_S2_12	12	0.869	63.5	573.6	74.5	673.0	631.0	1.173	23.3	2.60	1.8	9.2
FRO_S3_12	12	0.895	68.5	600.6	80.75	708.0	660.6	1.179	16.7	2.60	1.8	9.7
FRO_S1_16	16	1.536	110.5	564.7	134	684.8	621.2	1.213	25.0	4.37	2.4	8.7

Mill ID	Nominal Size, mm	Nominal Mass, W/L, kg/m	Load at Yield, kN	Yield Strength, MPa	Max. Load, kN	Tensile Strength, MPa	NS Requirement	UTS/YS ratio	Percentage Elongation, %	Bond Value, A _r , mm	Required Bond, mm	Total Elongation at Max. Force, %
FRO_S2_16	16	1.593	111.3	548.1	131.25	646.6	602.9	1.180	22.5	4.37	2.4	8.4
FRO_S3_16	16	1.555	110.0	555.2	135	681.3	610.7	1.227	21.3	4.37	2.4	8.7
FRO_S1_20	20	2.374	160.0	529.2	196	648.2	582.1	1.225	22.0	5.10	3.4	8.3
FRO_S2_20	20	2.480	162.0	512.7	200.5	634.6	565.0	1.238	25.0	5.10	3.4	11.0
FRO_S3_20	20	2.374	157.5	520.9	197	651.5	573.0	1.251	24.0	5.10	3.4	8.3
FRO_S1_25	25	3.782	286.0	593.6	341	707.8	653.0	1.192	20.8	5.79	4.25	7.0
FRO_S2_25	25	3.774	272.5	566.7	328	682.2	623.4	1.204	20.8	5.79	4.25	10.3
FRO_S3_25	25	3.706	240.5	509.4	294.5	623.8	565.0	1.225	25.8	5.79	4.25	7.0
FRO_S1_28	28	4.640	311.0	526.2	386	653.1	578.8	1.241	21.4	6.39	4.76	8.9
FRO_S2_28	28	4.775	321.0	527.7	399	656.0	580.5	1.243	21.4	6.39	4.76	6.0
FRO_S3_28	28	4.640	318.5	538.9	395	668.3	592.7	1.240	21.4	6.39	4.76	8.9

ANNEX III: STATISTICAL ANALYSIS RESULTS Fe500 TMT BARS

Fe500 TMT bar, 8 mm Diameter						
Descriptive Statistics	Mass per Meter Run, kg/m	Yield Strength, MPa	Tensile Strength, MPa	Percentage Elongation, %	UTS/YS ratio	Bond Value, A_r, mm
Mean	0.398	573.9	688.0	23.4	1.200	1.69
Standard Error	0.002	5.6	6.9	0.4	0.005	0.11
Coefficient of Variation	2.518	4.3	4.4	6.6	1.960	27.47
Standard Deviation	0.010	24.5	30.1	1.5	0.024	0.47
Sample Variance	0.000	599.6	909.0	2.4	0.001	0.22
Kurtosis	-1.12	1.9	2.5	-0.5	0.203	0.87
Skewness	-0.25	-1.1	-1.3	0.4	-0.407	0.88
Range	0.033	99.8	128.6	5.8	0.095	1.83
Minimum	0.379	506.0	601.6	20.8	1.148	1.06
Maximum	0.411	605.8	730.3	26.7	1.243	2.89
Count	19	19	19	19	19	19
Confidence Level (95.0%)	0.005	11.8	14.5	0.7	0.011	0.22
10 mm Fe 500 TMT Bar						
Descriptive Statistics	Mass per Meter Run, kg/m	Yield Strength, MPa	Tensile Strength, MPa	Percentage Elongation, %	UTS/YS ratio	Bond Value, A_r, mm
Mean	0.604	563.1	670.7	22.1	1.193	1.93
Standard Error	0.002	6.4	6.2	0.4	0.008	0.09
Coefficient of Variation	1.725	5.0	4.0	7.0	2.910	19.56
Standard Deviation	0.010	28.0	27.1	1.6	0.035	0.38
Sample Variance	0.000	786.3	736.6	2.4	0.001	0.14
Kurtosis	0.363	0.2	3.1	-0.2	-1.143	0.09
Skewness	0.957	0.7	-1.2	0.9	-0.055	-0.75
Range	0.035	109.9	117.7	5.3	0.116	1.42
Minimum	0.592	517.2	591.3	20.0	1.133	1.17
Maximum	0.627	627.1	708.9	25.3	1.249	2.59
Count	19	19	19	19	19	19
Confidence Level (95.0%)	0.005	13.5	13.1	0.7	0.017	0.18

Fe500 TMT Bar, 12 mm						
Descriptive Statistics	Mass per Meter Run, kg/m	Yield Strength, MPa	Tensile Strength, MPa	Percentage Elongation, %	UTS/YS ratio	Bond Value, A_r, mm
Mean	0.879	559.1	659.1	21.9	1.179	2.65
Standard Error	0.002	5.3	7.4	0.5	0.007	0.15
Coefficient of Variation	0.996	4.1	4.9	10.8	2.586	23.97
Standard Deviation	0.009	23.1	32.3	2.4	0.030	0.63
Sample Variance	0.000	535.0	1041.1	5.6	0.001	0.40
Kurtosis	-1.239	0.0	1.2	-1.0	0.306	-1.10
Skewness	0.145	0.4	-0.8	-0.3	-0.515	0.14
Range	0.030	84.8	136.0	7.2	0.126	1.89
Minimum	0.864	519.5	584.6	17.8	1.109	1.78
Maximum	0.894	604.3	720.5	25.0	1.235	3.67
Count	19	19	19	19	19	19
Confidence Level (95.0%)	0.004	11.1	15.6	1.1	0.015	0.31
Fe500 TMT bar, 16 mm						
Descriptive Statistics	Mass per Meter Run, kg/m	Yield Strength, MPa	Tensile Strength, MPa	Percentage Elongation, %	UTS/YS ratio	Bond Value, A_r, mm
Mean	1.553	544.8	650.6	21.9	1.195	3.65
Standard Error	0.003	3.8	5.7	0.3	0.006	0.22
Coefficient of Variations	0.887	3.0	3.8	5.7	2.345	26.88
Standard Deviation	0.014	16.4	24.9	1.2	0.028	0.98
Sample Variance	0.000	270.5	622.4	1.6	0.001	0.96
Kurtosis	0.603	-1.0	0.1	0.6	3.476	-0.64
Skewness	-0.483	-0.4	-0.4	-0.6	-1.215	0.09
Range	0.058	53.7	97.4	5.0	0.134	3.53
Minimum	1.519	517.4	599.4	18.8	1.113	1.95
Maximum	1.577	571.2	696.8	23.8	1.247	5.48
Count	19	19	19	19	19	19
Confidence Level (95.0%)	0.007	7.9	12.0	0.6	0.014	0.47

Fe500 TMT Bars, 20mm						
Descriptive Statistics	Mass per Meter Run, kg/m	Yield Strength, MPa	Tensile Strength, MPa	Percentage Elongation, %	UTS/YS ratio	Bond Value, Ar, mm
Mean	2.448	550.8	660.2	21.8	1.200	4.59
Standard Error	0.008	5.4	5.1	0.4	0.007	0.20
Coefficient of Variation	1.399	4.3	3.4	7.7	2.400	19.01
Standard Deviation	0.034	23.6	22.3	1.7	0.029	0.87
Sample Variance	0.001	557.1	497.6	2.8	0.001	0.76
Kurtosis	0.792	0.2	-0.9	1.1	2.092	-0.56
Skewness	0.826	0.7	-0.2	0.7	-0.903	0.50
Range	0.134	82.0	74.8	7.3	0.124	3.07
Minimum	2.392	519.0	624.0	18.7	1.122	3.42
Maximum	2.526	601.1	698.9	26.0	1.246	6.49
Count	19.000	19.0	19.0	19.0	19.000	19.00
Confidence Level (95.0%)	0.017	11.4	10.8	0.8	0.014	0.42
Fe500 TMT Bars, 25 mm						
Descriptive Statistics	Mass per Meter Run, kg/m	Yield Strength, MPa	Tensile Strength, MPa	Percentage Elongation, %	UTS/YS ratio	Bond Value, Ar, mm
Mean	3.813	545.5	657.5	22.2	1.206	5.23
Standard Error	0.012	7.1	6.1	0.5	0.007	0.25
Coefficient of Variation	1.181	4.9	3.5	7.6	2.084	18.04
Standard Deviation	0.045	26.7	22.8	1.7	0.025	0.94
Sample Variance	0.002	713.6	519.8	2.9	0.001	0.89
Kurtosis	-0.893	-1.4	-1.4	0.2	1.937	2.72
Skewness	-0.050	0.2	0.0	-0.3	-0.958	1.58
Range	0.135	83.1	66.4	6.1	0.097	3.46
Minimum	3.749	506.9	625.2	18.9	1.143	4.25
Maximum	3.883	590.0	691.6	25.0	1.240	7.72
Count	14	14	14	14	14	14
Confidence Level (95.0%)	0.026	15.4	13.2	1.0	0.015	0.54

Fe500 TMT Bar, 28 mm						
Descriptive Statistics	Mass per Meter Run, kg/m	Yield Strength, MPa	Tensile Strength, MPa	Percentage Elongation, %	UTS/YS ratio	Bond Value, Ar, mm
Mean	4.755	543.4	659.9	20.2	1.216	5.97
Standard Error	0.023	8.4	6.6	0.6	0.010	0.36
Coefficient of Variation	1.293	4.1	2.7	7.3	2.126	15.82
Standard Deviation	0.061	22.2	17.5	1.5	0.026	0.94
Sample Variance	0.004	494.4	306.2	2.2	0.001	0.89
Kurtosis	-1.860	-1.8	-1.5	-1.0	0.048	-0.68
Skewness	0.327	0.5	-0.3	-0.3	0.110	0.31
Range	0.158	55.0	44.8	4.0	0.079	2.63
Minimum	4.682	521.2	637.0	17.9	1.177	4.81
Maximum	4.840	576.2	681.7	21.9	1.256	7.44
Count	7	7	7	7	7	7
Confidence Level (95.0%)	0.057	20.6	16.2	1.4	0.024	0.87
Fe500 TMT Bar, 32 mm						
Descriptive Statistics	Mass per Meter Run, kg/m	Yield Strength, MPa	Tensile Strength, MPa	Percentage Elongation, %	UTS/YS ratio	Bond Value, Ar, mm
Mean	6.217	524.8	645.6	20.8	1.230	6.43
Standard Error	0.016	4.5	3.4	0.5	0.007	0.41
Coefficient of Variation	0.648	2.1	1.3	6.2	1.391	15.46
Standard Deviation	0.040	10.9	8.4	1.3	0.017	0.99
Sample Variance	0.002	118.9	70.5	1.7	0.000	0.99
Kurtosis	1.074	-1.2	0.6	-0.3	-1.946	-0.75
Skewness	1.103	0.5	-0.5	-0.7	0.687	0.88
Range	0.109	28.6	24.7	3.5	0.039	2.46
Minimum	6.177	512.3	632.3	18.8	1.215	5.53
Maximum	6.286	540.9	657.0	22.3	1.253	7.99
Count	6	6	6	6	6	6
Confidence Level (95.0%)	0.042	11.4	8.8	1.4	0.018	1.04

ANNEX IV: STATISTICAL ANALYSIS RESULTS Fe500D TMT BARS

Fe500D TMT bar, 8 mm							
Descriptive Statistics	Mass per Meter Run, kg/m	Yield Strength, MPa	Tensile Strength, MPa	Percentage Elongation, %	UTS/YS ratio	Bond Value, Ar, mm	Total Elongation at Max. Force, %
Mean	0.397	574.4	670.2	23.6	1.166	1.30	6.14
Standard Error	0.008	18.0	23.5	1.0	0.014	0.20	0.62
Coefficient of Variation	3.366	5.4	6.1	7.3	2.084	26.86	17.35
Standard Deviation	0.013	31.2	40.8	1.7	0.024	0.35	1.07
Sample Variance	0.000	974.6	1662.1	3.0	0.001	0.12	1.13
Skewness	-1.661	-1.5	-1.5	-1.3	1.457	1.62	1.48
Range	0.024	58.8	77.0	3.3	0.046	0.64	2.01
Minimum	0.381	539.0	623.9	21.7	1.148	1.06	5.34
Maximum	0.406	597.7	700.9	25.0	1.194	1.70	7.35
Count	3	3	3	3	3	3	3
Confidence Level (95.0%)	0.033	77.6	101.3	4.3	0.060	0.87	2.65

Fe500D TMT bar, 10 mm							
Descriptive Statistics	Mass per Meter Run, kg/m	Yield Strength, MPa	Tensile Strength, MPa	Percentage Elongation, %	UTS/YS ratio	Bond Value, A _r , mm	Total Elongation at Max. Force, %
Mean	0.608	548.5	652.1	22.9	1.189	2.16	6.51
Standard Error	0.008	18.4	20.6	0.2	0.013	0.19	0.64
Coefficient of Variation	2.305	5.8	5.5	1.7	1.825	15.10	16.92
Standard Deviation	0.014	31.8	35.7	0.4	0.022	0.33	1.10
Sample Variance	0.000	1011.5	1271.8	0.1	0.000	0.11	1.21
Skewness	1.592	-1.4	0.0	1.7	-1.721	-1.73	1.39
Range	0.026	60.4	71.3	0.7	0.038	0.57	2.10
Minimum	0.598	512.5	616.5	22.7	1.164	1.78	5.66
Maximum	0.624	572.9	687.8	23.3	1.203	2.35	7.76
Count	3	3	3	3	3	3	3
Confidence Level (95.0%)	0.035	79.0	88.6	1.0	0.054	0.81	2.74

Fe500D TMT bar, 12 mm							
Descriptive Statistics	Mass per Meter Run, kg/m	Yield Strength, MPa	Tensile Strength, MPa	Percentage Elongation, %	UTS/YS ratio	Bond Value, A _r , mm	Total Elongation at Max. Force, %
Mean	0.875	560.5	679.0	22.2	1.213	3.47	10.96
Standard Error	0.007	13.3	9.9	0.6	0.017	0.55	0.67
Coefficient of Variation	1.441	4.1	2.5	4.3	2.448	27.36	10.65
Standard Deviation	0.013	23.0	17.2	1.0	0.030	0.95	1.17
Sample Variance	0.000	527.2	295.9	0.9	0.001	0.90	1.36
Skewness	-1.731	1.7	-0.5	-1.7	0.372	0.67	-0.29
Range	0.022	40.0	34.3	1.7	0.059	1.88	2.33
Minimum	0.860	547.1	661.0	21.1	1.184	2.60	9.76
Maximum	0.882	587.1	695.3	22.8	1.243	4.49	12.09
Count	3	3	3	3	3	3	3
Confidence Level (95.0%)	0.031	57.0	42.7	2.4	0.074	2.36	2.90

Fe500D TMT bar, 16 mm							
Descriptive Statistics	Mass per Meter Run, kg/m	Yield Strength, MPa	Tensile Strength, MPa	Percentage Elongation, %	UTS/YS ratio	Bond Value, A_r, mm	Total Elongation at Max. Force, %
Mean	1.554	579.8	695.2	21.8	1.199	3.57	8.66
Standard Error	0.004	12.3	13.3	1.1	0.005	0.45	1.10
Coefficient of Variation	0.412	3.7	3.3	8.8	0.715	22.03	21.96
Standard Deviation	0.006	21.3	23.1	1.9	0.009	0.79	1.90
Sample Variance	0.000	455.7	532.5	3.7	0.000	0.62	3.62
Skewness	1.712	-1.2	-0.5	-1.7	-0.821	0.10	0.15
Range	0.011	41.2	45.9	3.3	0.017	1.57	3.80
Minimum	1.550	556.0	670.9	19.6	1.190	2.80	6.79
Maximum	1.562	597.2	716.9	22.9	1.207	4.37	10.60
Count	3	3	3	3	3	3	3
Confidence Level (95.0%)	0.016	53.0	57.3	4.8	0.021	1.96	4.73

Fe500D TMT bars, 20 mm							
Descriptive Statistics	Mass per Meter Run, kg/m	Yield Strength, MPa	Tensile Strength, MPa	Percentage Elongation, %	UTS/YS ratio	Bond Value, A _r , mm	Total Elongation at Max. Force, %
Mean	2.427	554.4	670.7	21.8	1.211	4.95	8.25
Standard Error	0.010	16.8	14.5	1.0	0.016	0.16	0.54
Coefficient of Variation	0.742	5.2	3.7	7.9	2.296	5.68	11.37
Standard Deviation	0.018	29.1	25.1	1.7	0.028	0.28	0.94
Sample Variance	0.000	844.0	627.7	2.9	0.001	0.08	0.88
Skewness	0.254	-1.7	-0.3	1.1	-0.330	-1.73	0.22
Range	0.036	52.1	50.0	3.3	0.056	0.49	1.87
Minimum	2.409	520.9	644.8	20.3	1.182	4.62	7.34
Maximum	2.445	573.0	694.8	23.7	1.238	5.11	9.21
Count	3	3	3	3	3	3	3
Confidence Level (95.0%)	0.045	72.2	62.2	4.2	0.069	0.70	2.33

Fe500D TMT bar, 25 mm							
Descriptive Statistics	Mass per Meter Run, kg/m	Yield Strength, MPa	Tensile Strength, MPa	Percentage Elongation, %	UTS/YS ratio	Bond Value, A_r, mm	Total Elongation at Max. Force, %
Mean	3.793	569.0	688.2	21.6	1.210	5.52	8.06
Standard Error	0.023	6.2	9.7	1.1	0.007	0.38	0.43
Coefficient of Variation	1.029	1.9	2.5	8.6	1.008	11.81	9.16
Standard Deviation	0.039	10.8	16.9	1.8	0.012	0.65	0.74
Sample Variance	0.002	116.9	285.1	3.4	0.000	0.43	0.54
Skewness	0.143	-1.6	0.0	-1.7	1.091	-1.54	-0.32
Range	0.078	20.1	33.8	3.3	0.024	1.22	1.47
Minimum	3.754	556.6	671.2	19.4	1.200	4.78	7.30
Maximum	3.832	576.6	705.0	22.8	1.223	6.00	8.77
Count	3	3	3	3	3	3	3
Confidence Level (95.0%)	0.097	26.9	41.9	4.6	0.030	1.62	1.83

Fe500D TMT bar, 28 mm							
Descriptive Statistics	Mass per Meter Run, kg/m	Yield Strength, MPa	Tensile Strength, MPa	Percentage Elongation, %	UTS/YS ratio	Bond Value, A_r, mm	Total Elongation at Max. Force, %
Mean	4.755	563.7	683.8	20.5	1.214	5.77	8.23
Standard Error	0.039	19.9	14.3	0.5	0.017	0.36	0.62
Coefficient of Variation	1.423	6.1	3.6	4.2	2.486	10.77	12.95
Standard Deviation	0.068	34.5	24.8	0.9	0.030	0.62	1.07
Sample Variance	0.005	1191.1	615.5	0.7	0.001	0.39	1.14
Skewness	-0.356	0.4	0.1	1.2	-0.779	0.06	1.09
Range	0.135	68.8	49.6	1.7	0.060	1.24	2.08
Minimum	4.685	530.9	659.1	19.8	1.182	5.15	7.33
Maximum	4.820	599.7	708.7	21.4	1.241	6.39	9.40
Count	3	3	3	3	3	3	3
Confidence Level (95.0%)	0.168	85.7	61.6	2.1	0.075	1.54	2.65

Fe500D TMT bar, 32 mm							
Descriptive Statistics	Mass per Meter Run, kg/m	Yield Strength, MPa	Tensile Strength, MPa	Percentage Elongation, %	UTS/YS ratio	Bond Value, A_r, mm	Total Elongation at Max. Force, %
Mean	6.242	574.0	689.6	21.3	1.202	6.87	9.89
Standard Error	0.012	23.0	21.6	0.0	0.011	0.29	0.60
Coefficient of Variation	0.273	5.7	4.4	0.0	1.266	6.05	8.59
Standard Deviation	0.017	32.5	30.5	0.0	0.015	0.42	0.85
Sample Variance	0.000	1057.1	929.1	0.0	0.000	0.17	0.72
Range	0.024	46.0	43.1	0.0	0.022	0.59	1.20
Minimum	6.230	551.0	668.1	21.3	1.191	6.58	9.29
Maximum	6.254	596.9	711.2	21.3	1.213	7.16	10.49
Count	2	2	2	2	2	2	2
Confidence Level (95.0%)	0.153	292.1	273.9	0.0	0.137	3.73	7.64

ANNEX V: OBSERVATION SHEET USED FOR TENSILE DATA

Company Name:

Date:

Grade:

Sam ple No.	Nominal Dia.	Mass , g	Length, mm	Yield Force, kN	Tensile Force, kN	Original G.L., mm	Final G.L., mm	Fe500D	
								OGL	FGL
1	8 mm								
2									
3									
1	10 mm								
2									
3									
1	12 mm								
2									
3									
1	16 mm								
2									
3									
1	20 mm								
2									
3									
1	25 mm								
2									
3									
1	28 mm								
2									
3									
1	32 mm								
2									
3									

Bond Test Parameters for Calculation of A_r

Mill ID:

Date:

Grade:

S. No.	Nominal Diameter (Φ) mm	Number of Transverse Ribs (n_{tr})	Experimental Length ($L > 10\Phi$) mm	Number of tr. Ribs within (N_{tr})	Average Angle (θ) Degrees		Length of tr. Rib (l_{tr}) mm	Height of tr. Rib (d_{tr}) mm												
					θ_1	θ_2		1	2	3	4	5	6	7	8	9	10			
1	8	2		20																
2	10	2		20																
3	12	2		20																
4	16	2		20																
5	20	2		20																
6	25	2		20																
7	28	2		20																
8	32	2		20																
Misc (.....)																				

BEND AND REBEND TEST DATA SHEET

Mill ID:

BEND TEST (NS: 333:2050)

Diameter of Deformed Bar	8	10	12	16	20	25	28	32
Diameter of Mandrel	32	40	48	64	80	125	140	160
Roller Spacing	56	70	84	112	140	200	224	256
Status of Test								

RE-BEND TEST

Diameter of Deformed Bar	8	10	12	16	20	25	28	32
Diameter of Mandrel	40	50	84	112	140	175	196	224
Roller Spacing	64	80	120	160	200	250	280	320
Status of Test								

For Re-bend Test First Bent to 135°
 Boil Water (@100°C) For 30
 Minutes.
 Allowed to Cool
 Bent Back 157.5°.

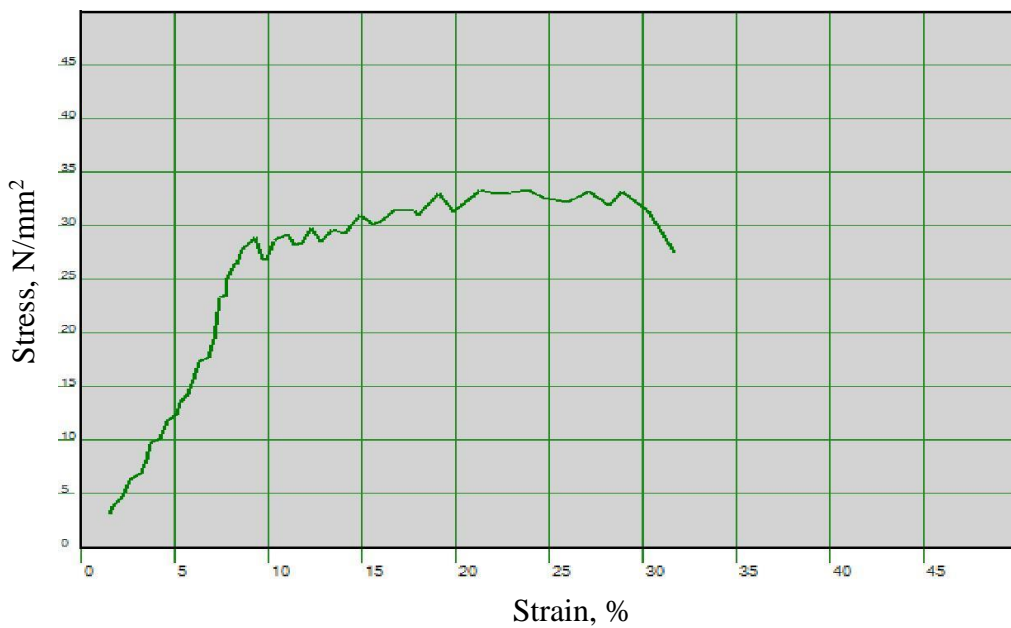
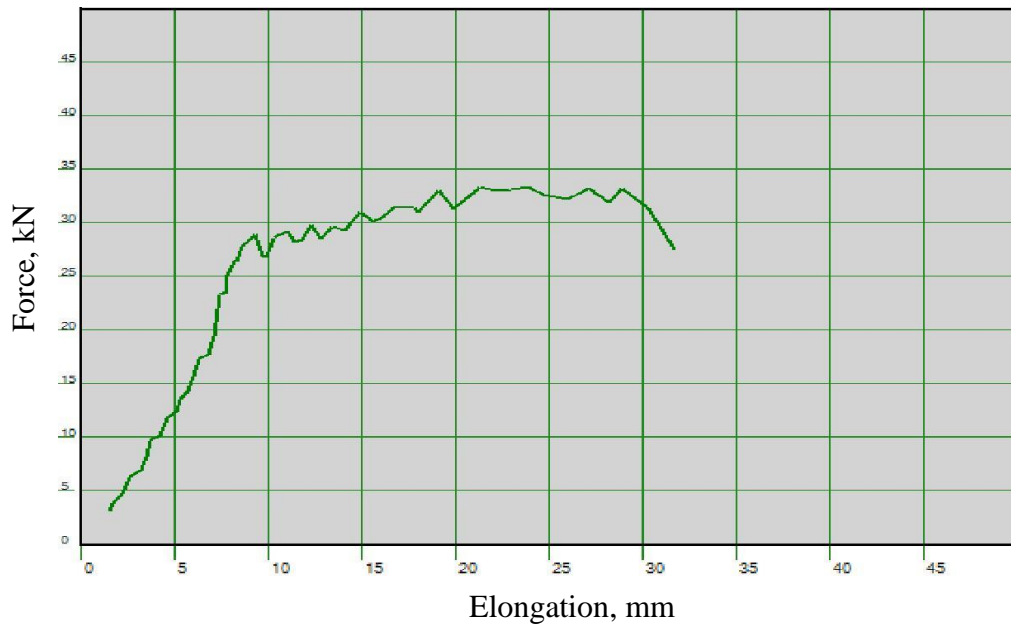
ANNEX VI: BOND TEST CALCULATION BY AREA OF PROJECTION



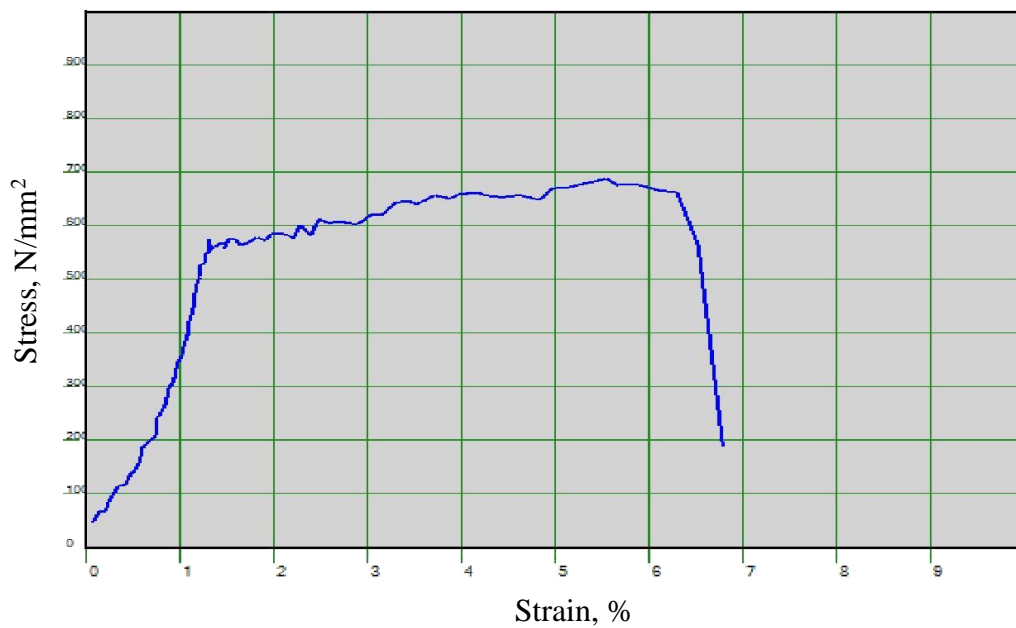
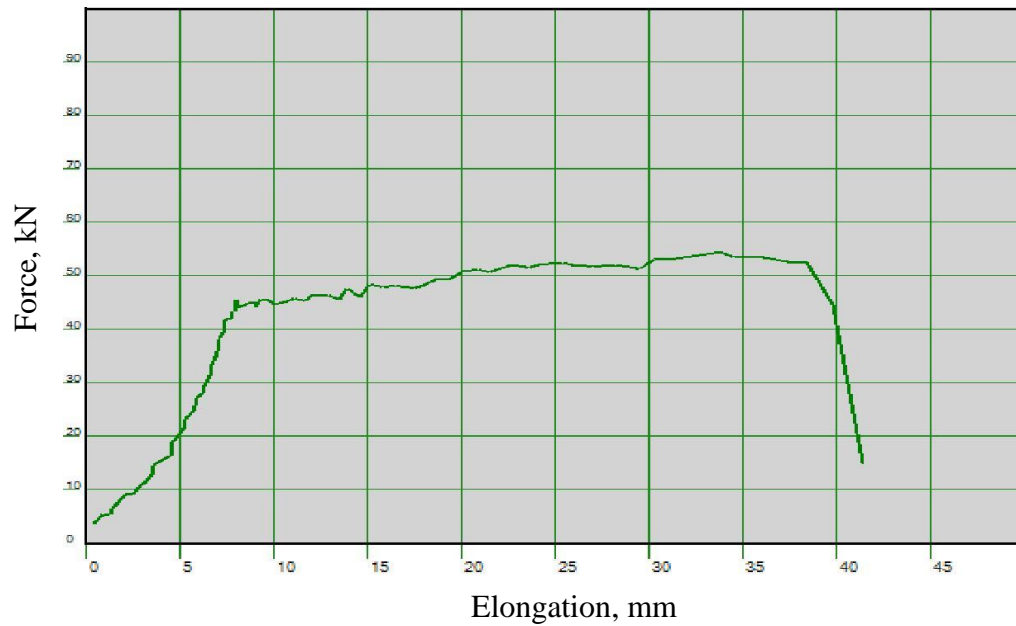
Figure VI.1 Bond test by area of projection method

ANNEX VII: HEICO UTM TEST RESULTS

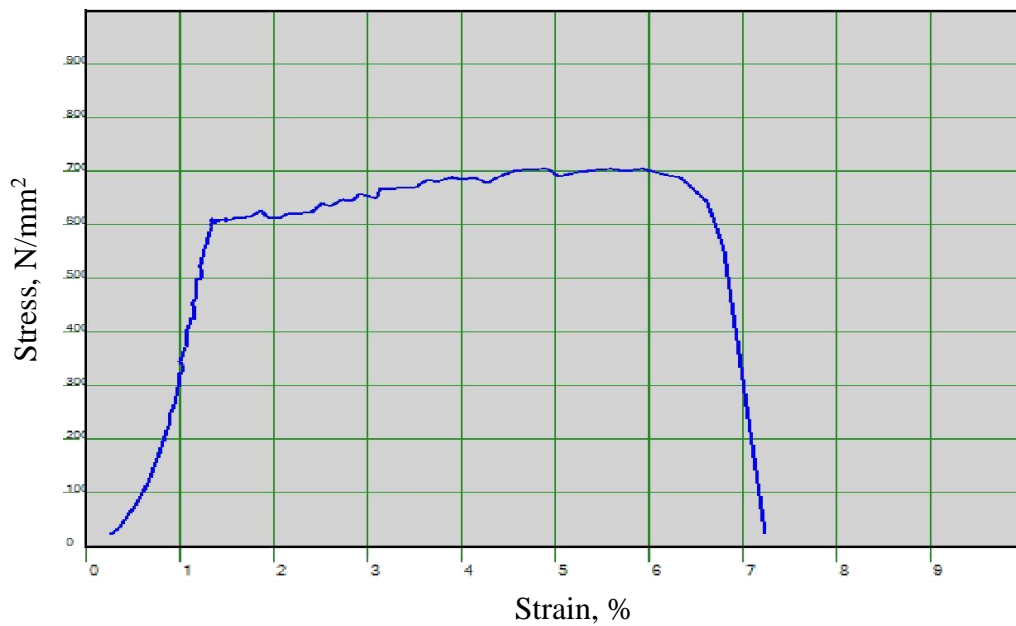
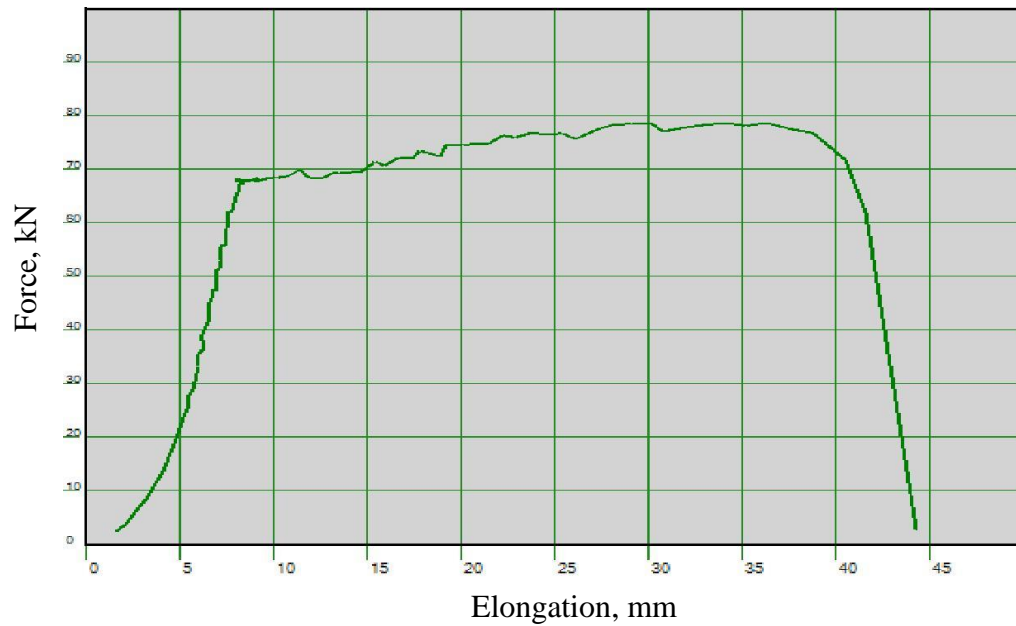
Sample Description		Test Results	
Test Type	Tension/JS_S2	Peak Load (kN)	33.3
Test Date	12/Feb/2019_8mm	Peak Stress (N/mm ²)	674.376
Sample Type	TMT	Disp. at Peak Load (mm)	21.3
Length (mm)	614	Strain at Peak Stress (%)	3.469
Mass (g)	238	Yield Load (kN)	26.889
Sample Area (mm ²)	49.38	Yield Point Extension (mm)	9.81
		Yield Stress (N/mm ²)	544.543



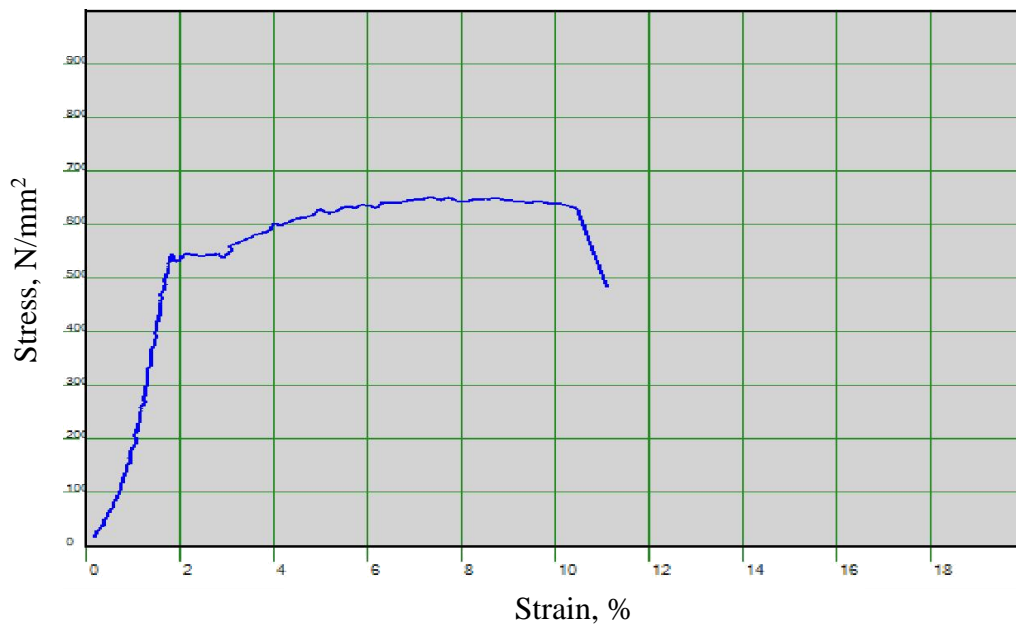
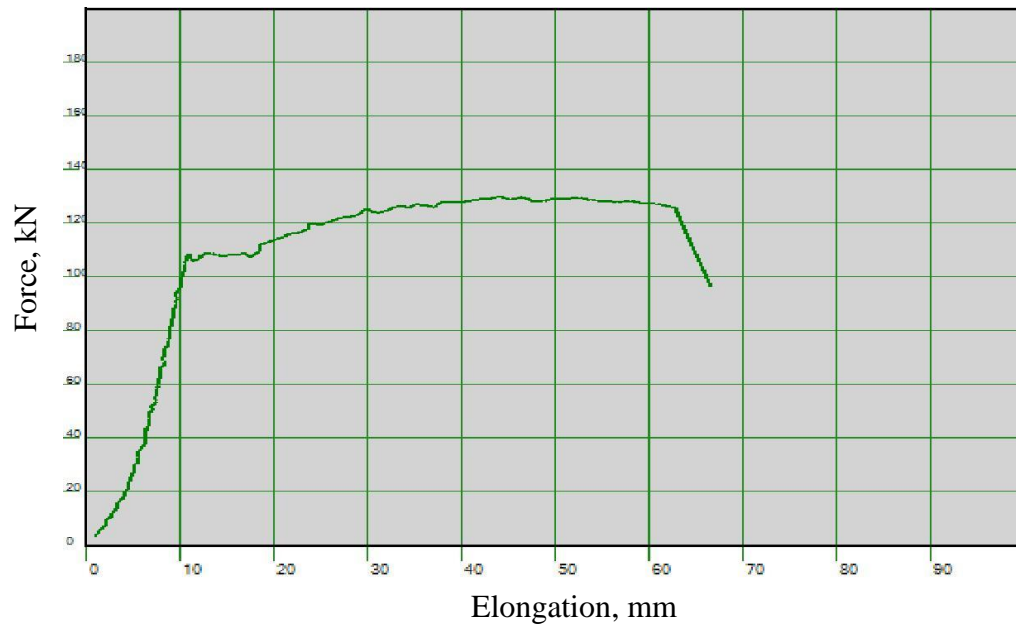
Sample Description		Test Results	
Test Type	Tension/JS_S2	Peak Load (kN)	54.4
Test Date	12/Feb/2019_10m	Peak Stress (N/mm ²)	687.32
Sample Type	TMT	Disp. at Peak Load (mm)	33.8
Length (mm)	610	Strain at Peak Stress (%)	5.541
Mass (g)	379	Yield Load (kN)	45.778
Sample Area (mm ²)	79.15	Yield Point Extension (mm)	11.51
		Yield Stress (N/mm ²)	578.385



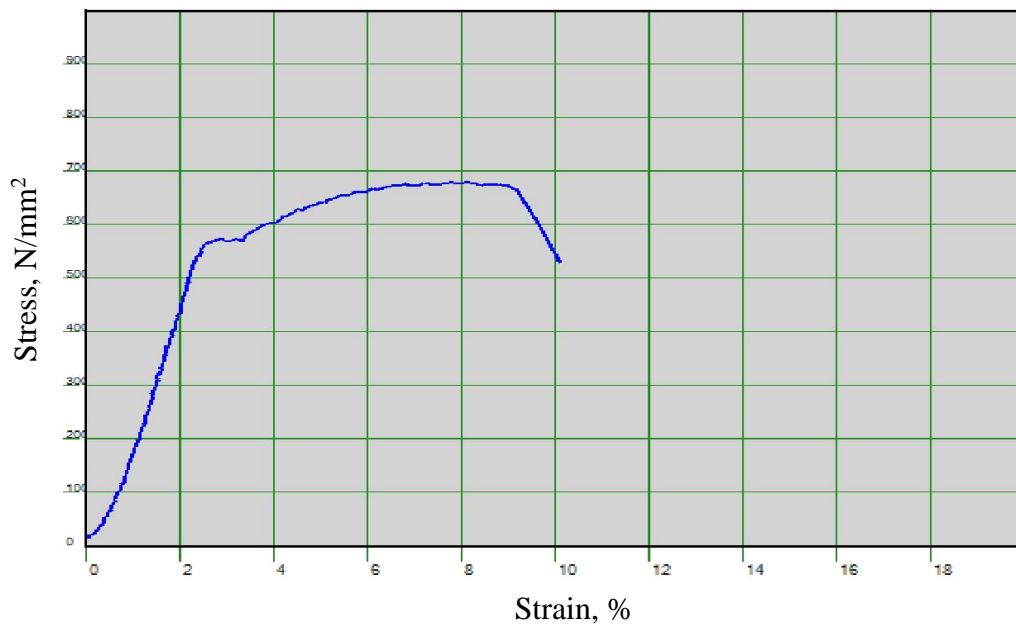
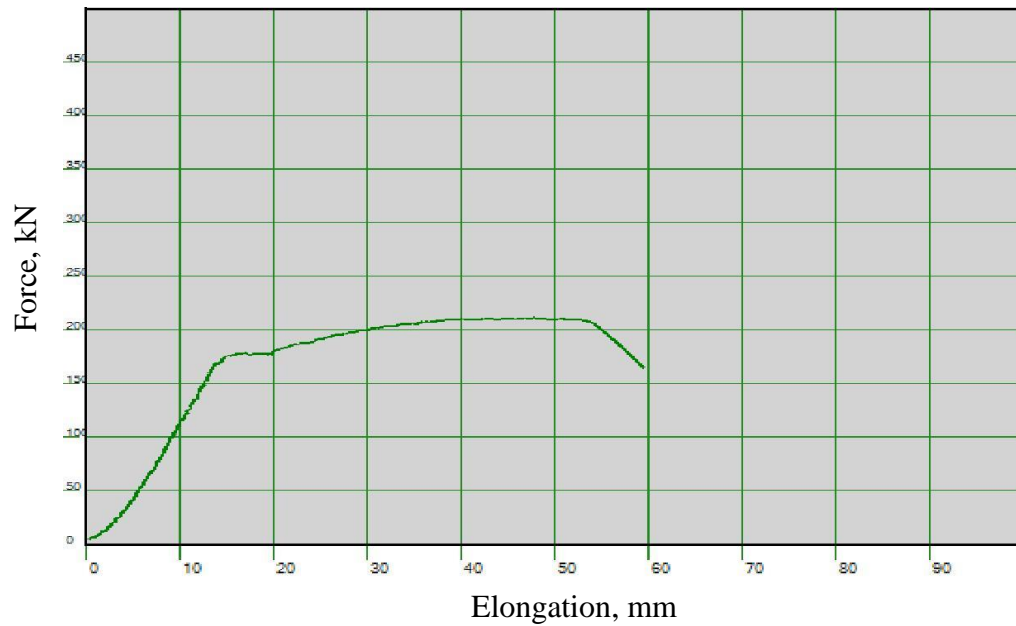
Sample Description		Test Results	
Test Type	Tension/JS_S2	Peak Load (kN)	78.6
Test Date	12/Feb/2019_12m	Peak Stress (N/mm ²)	704.497
Sample Type	TMT	Disp. at Peak Load (mm)	30.1
Length (mm)	612	Strain at Peak Stress (%)	4.918
Mass (g)	536	Yield Load (kN)	68.667
Sample Area (mm ²)	111.57	Yield Point Extension (mm)	11.83
		Yield Stress (N/mm ²)	615.467



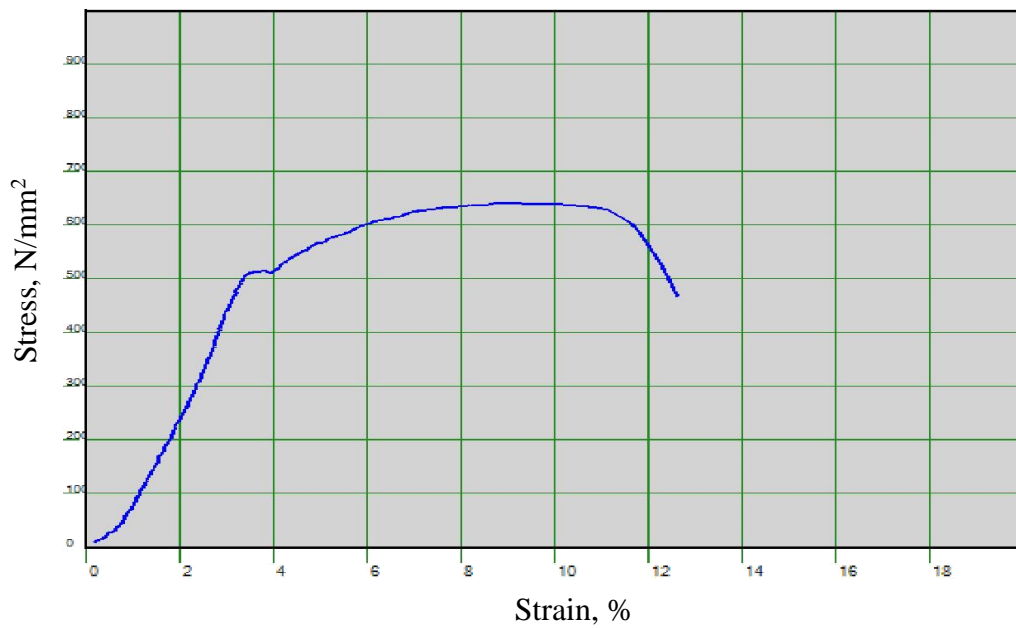
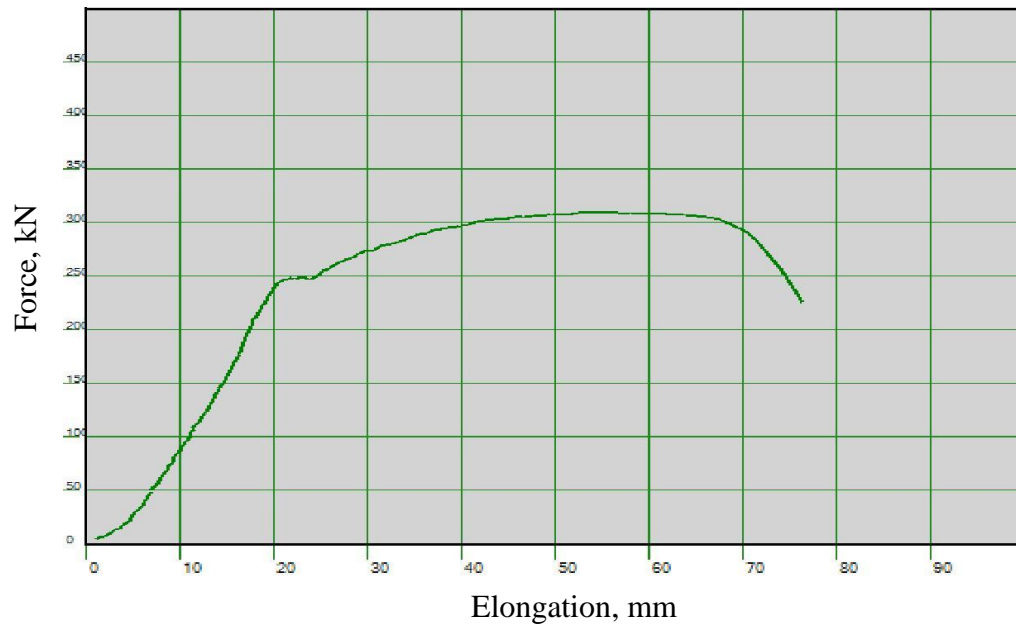
Sample Description		Test Results	
Test Type	Tension/JS_S2	Peak Load (kN)	129.9
Test Date	12/Feb/2019_16m	Peak Stress (N/mm ²)	651.575
Sample Type	TMT	Disp. at Peak Load (mm)	44.1
Length (mm)	600	Strain at Peak Stress (%)	7.35
Mass (g)	939	Yield Load (kN)	108
Sample Area (mm ²)	199.36	Yield Point Extension (mm)	17.48
		Yield Stress (N/mm ²)	541.725



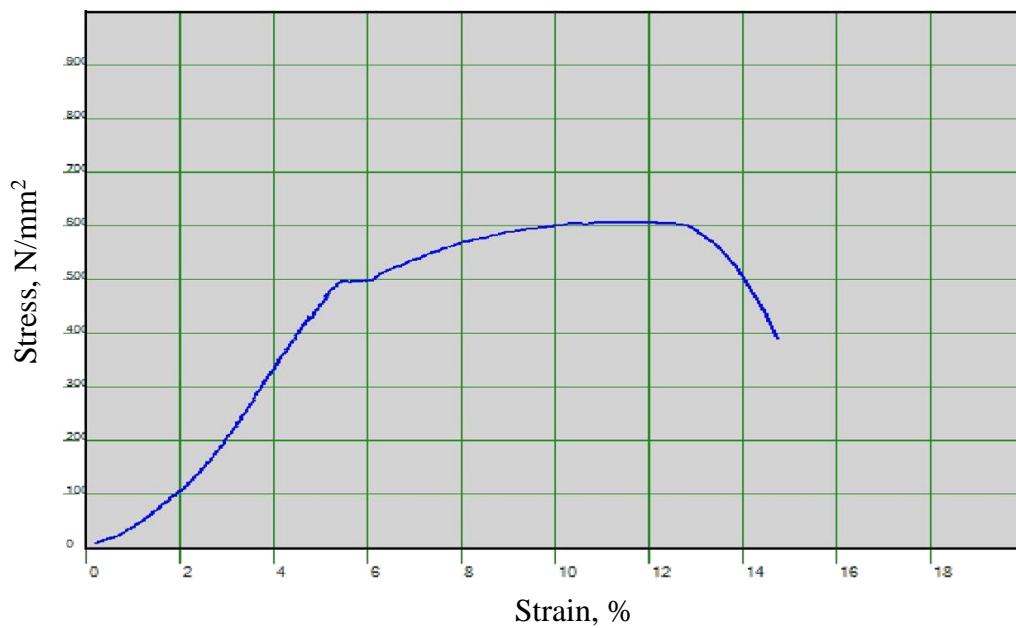
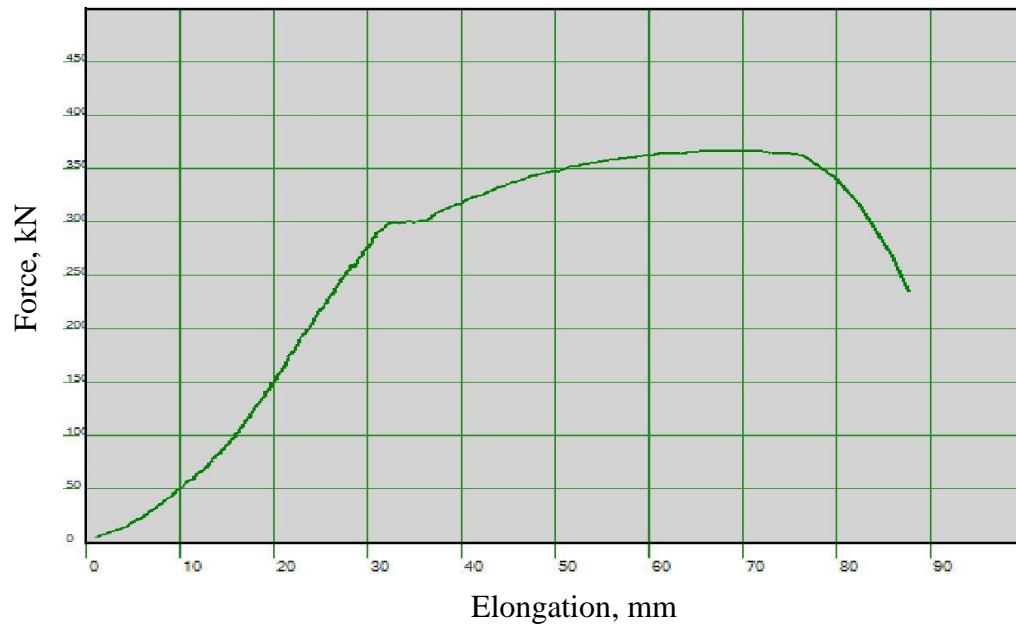
Sample Description		Test Results	
Test Type	Tension/JS_S2	Peak Load (kN)	211.1
Test Date	12/Feb/2019_20m	Peak Stress (N/mm ²)	678.756
Sample Type	TMT	Disp. at Peak Load (mm)	47.7
Length (mm)	589	Strain at Peak Stress (%)	8.098
Mass (g)	1438	Yield Load (kN)	176.667
Sample Area (mm ²)	311.01	Yield Point Extension (mm)	19.83
		Yield Stress (N/mm ²)	568.043



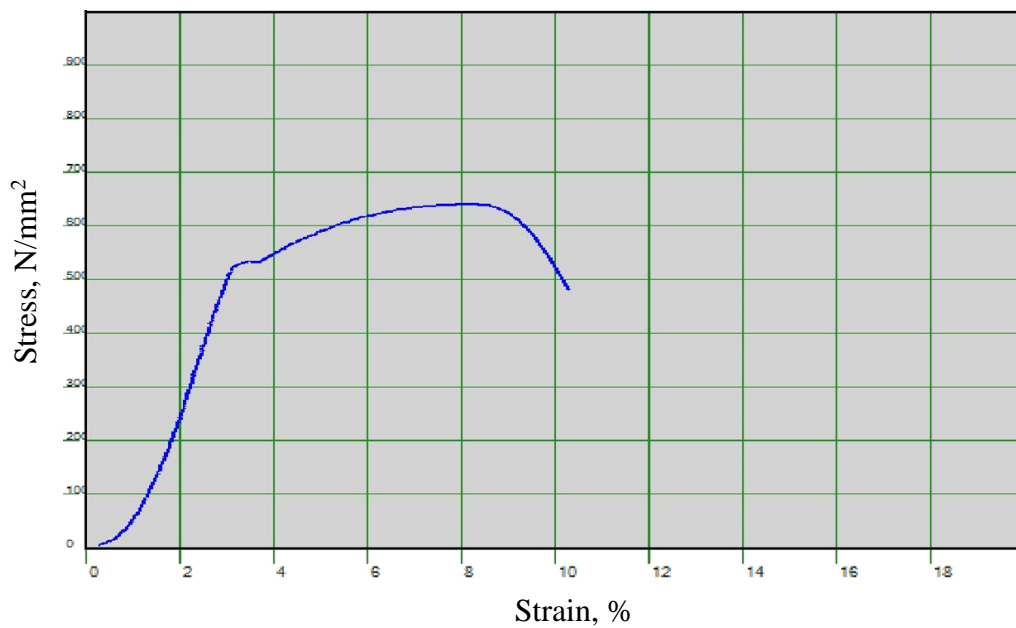
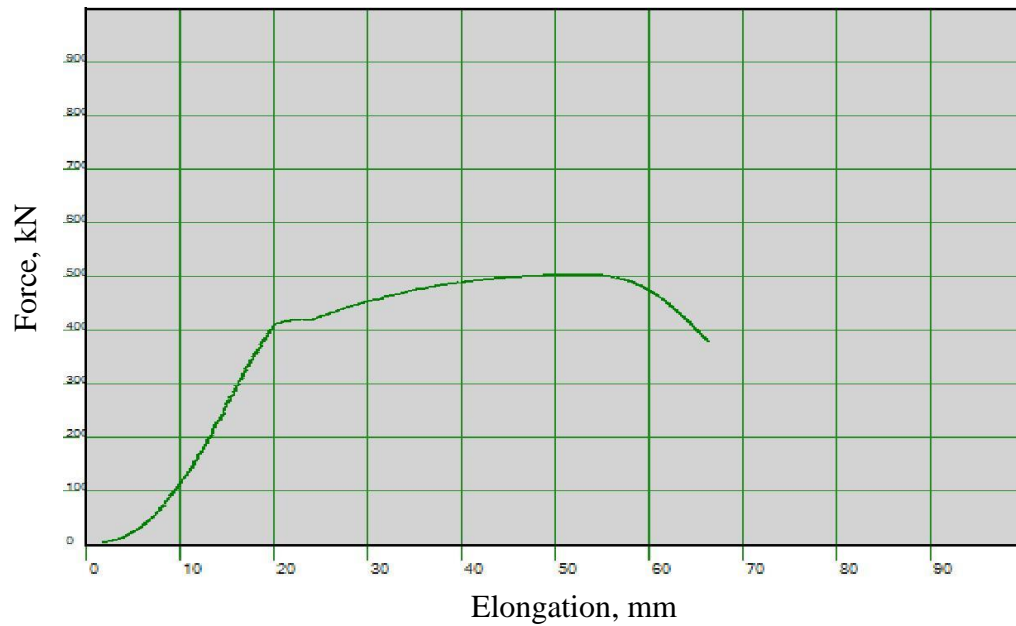
Sample Description		Test Results	
Test Type	Tension/JS_S2	Peak Load (kN)	309.5
Test Date	12/Feb/2019_25m	Peak Stress (N/mm ²)	640.755
Sample Type	TMT	Disp. at Peak Load (mm)	52.9
Length (mm)	605	Strain at Peak Stress (%)	8.744
Mass (g)	2294	Yield Load (kN)	247.778
Sample Area (mm ²)	483.02	Yield Point Extension (mm)	24.09
		Yield Stress (N/mm ²)	512.972



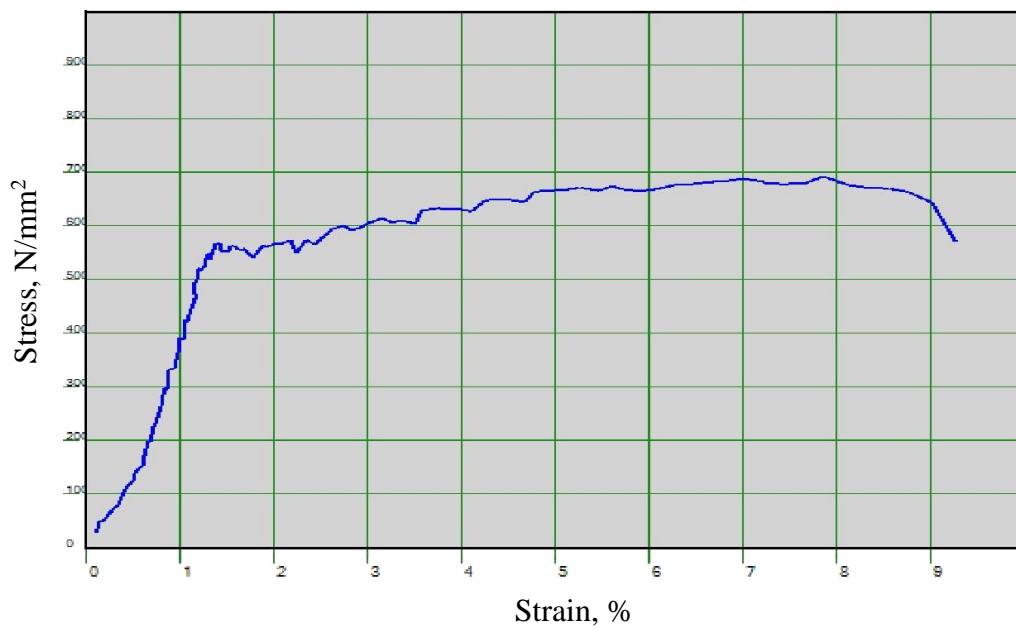
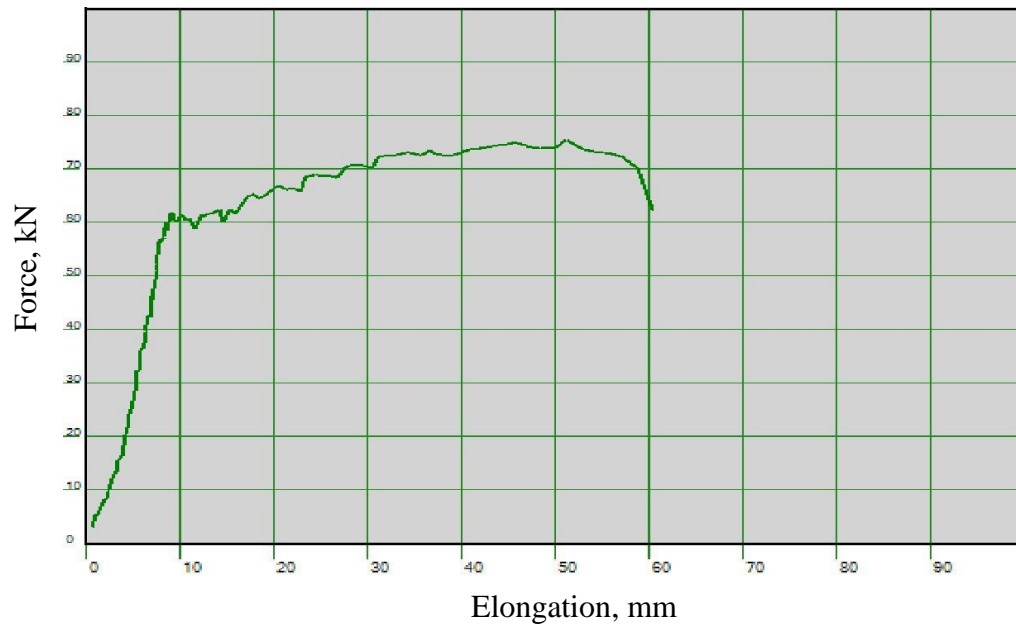
Sample Description		Test Results	
Test Type	Tension/JS_S2	Peak Load (kN)	366.6
Test Date	12/Feb/2019_28m	Peak Stress (N/mm ²)	607.844
Sample Type	TMT	Disp. at Peak Load (mm)	66.7
Length (mm)	595	Strain at Peak Stress (%)	11.21
Mass (g)	2817	Yield Load (kN)	311.111
Sample Area (mm ²)	603.11	Yield Point Extension (mm)	37.53
		Yield Stress (N/mm ²)	515.84



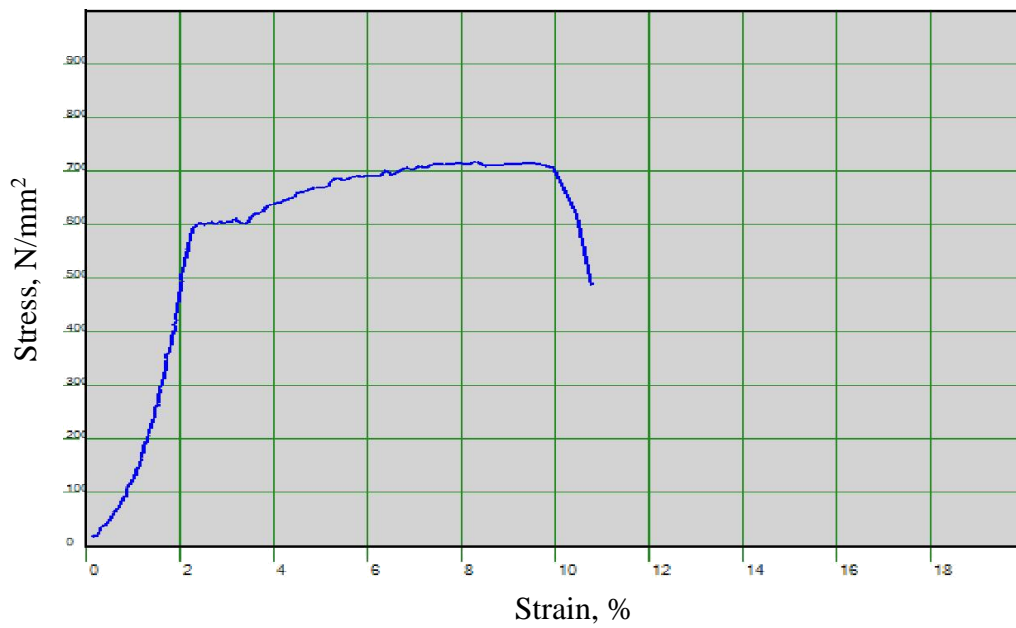
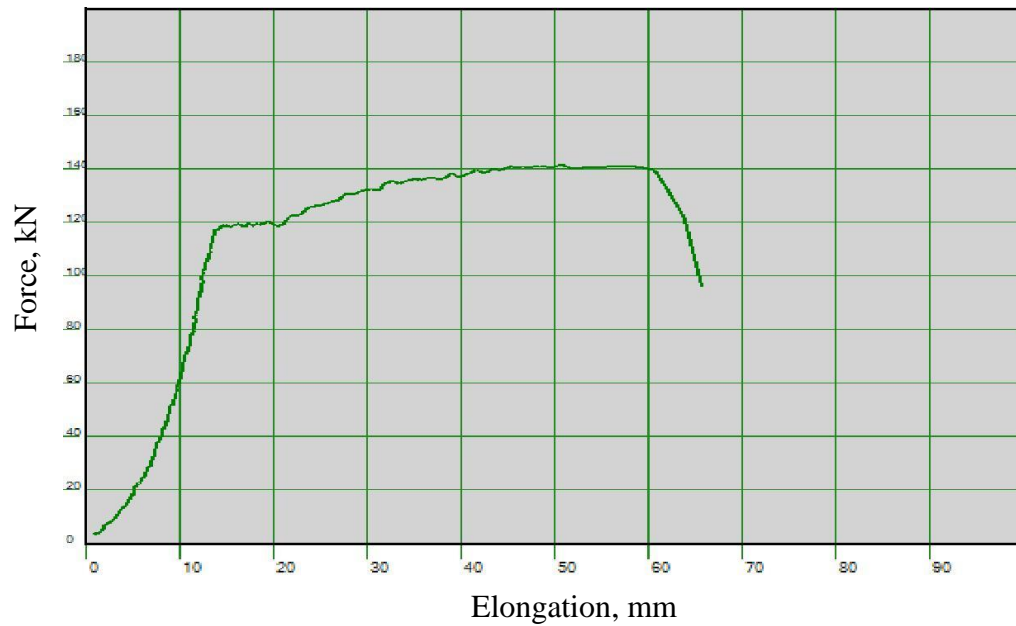
Sample Description		Test Results	
Test Type	Tension/JS_S2	Peak Load (kN)	503.4
Test Date	12/Feb/2019_32m	Peak Stress (N/mm ²)	640.573
Sample Type	TMT	Disp. at Peak Load (mm)	51.3
Length (mm)	645	Strain at Peak Stress (%)	7.953
Mass (g)	3979	Yield Load (kN)	417.778
Sample Area (mm ²)	785.86	Yield Point Extension (mm)	24.09
		Yield Stress (N/mm ²)	531.62



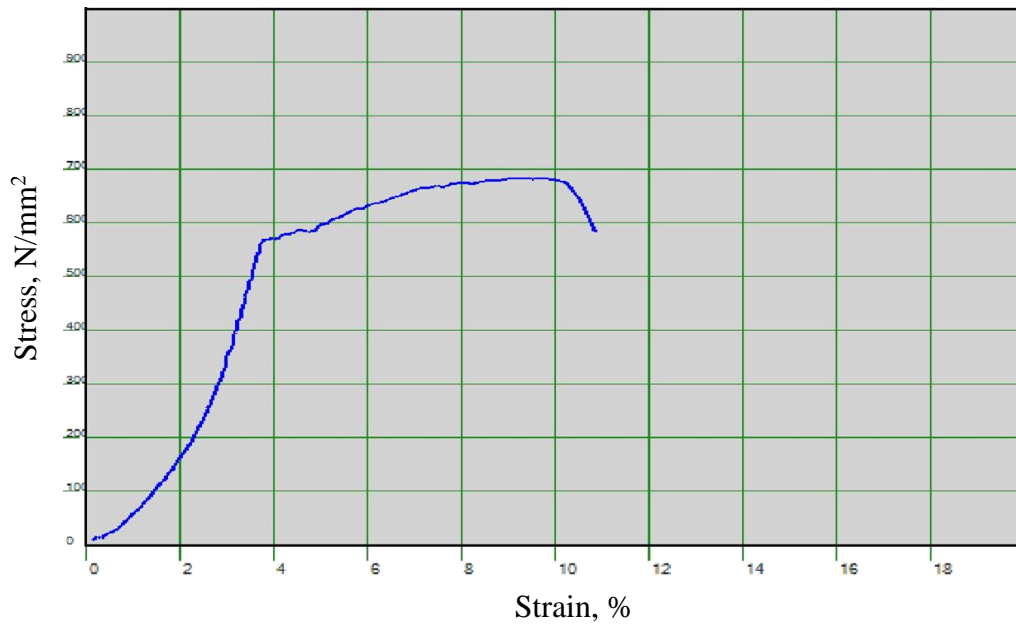
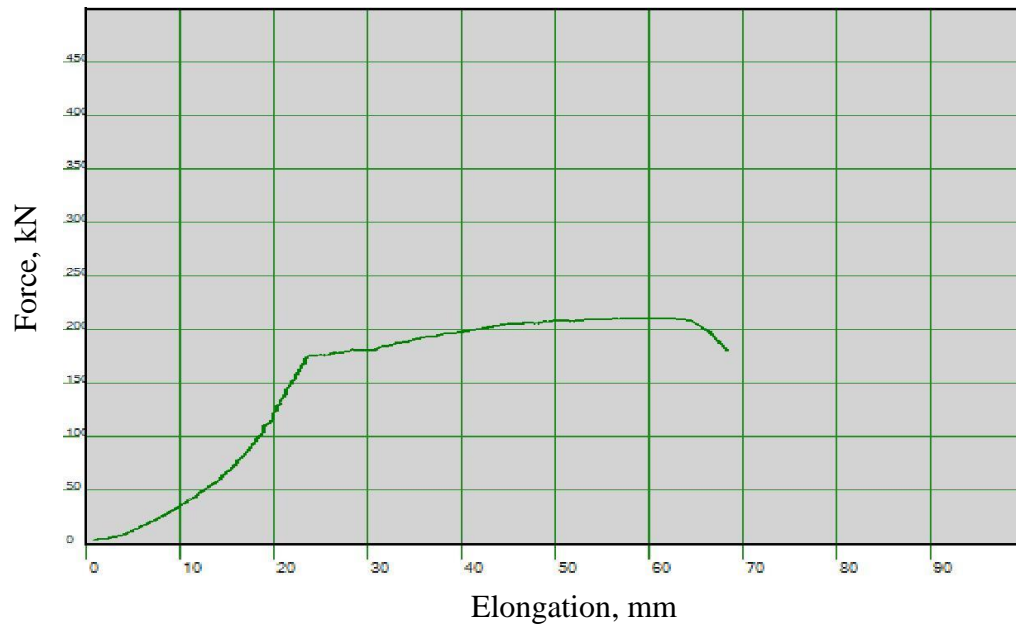
Sample Description		Test Results	
Test Type	Tension/RHN_S2	Peak Load (kN)	75.4
Test Date	12/Feb/2019_12m	Peak Stress (N/mm ²)	692.219
Sample Type	TMT	Disp. at Peak Load (mm)	51.2
Length (mm)	652	Strain at Peak Stress (%)	7.853
Mass (g)	557.5	Yield Load (kN)	61.111
Sample Area (mm ²)	108.93	Yield Point Extension (mm)	15.14
		Yield Stress (N/mm ²)	561.037



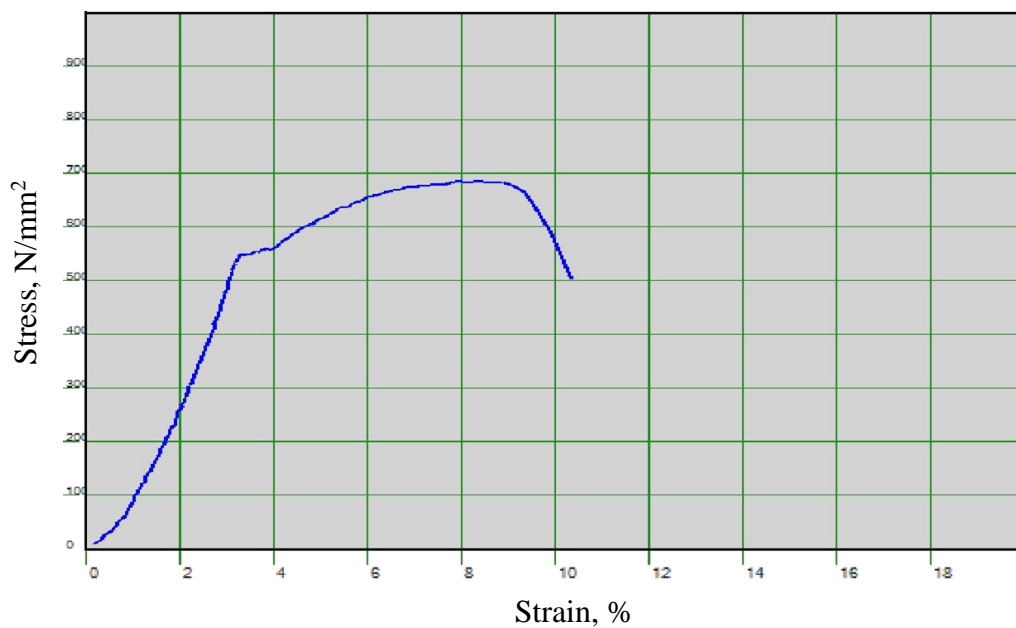
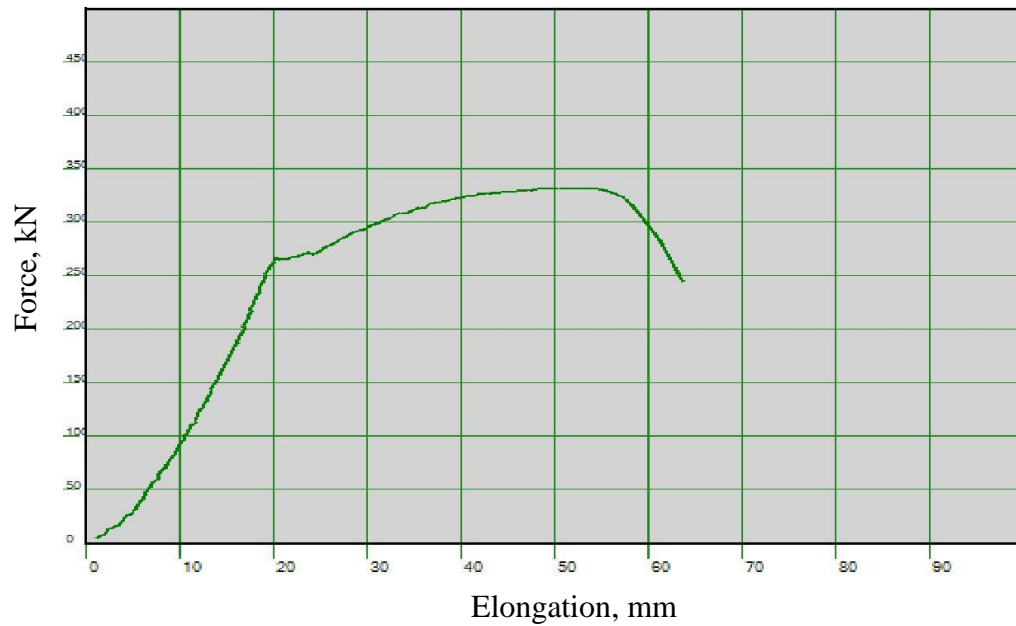
Sample Description		Test Results	
Test Type	Tension/RHN_S2	Peak Load (kN)	141.6
Test Date	12/Feb/2019_16m	Peak Stress(N/mm ²)	717.514
Sample Type	TMT	Disp. at Peak Load (mm)	50.7
Length (mm)	610	Strain at Peak Stress (%)	8.311
Mass (g)	945	Yield Load (kN)	119.111
Sample Area (mm ²)	197.35	Yield Point Extension (mm)	20.68
		Yield Stress (N/mm ²)	603.558



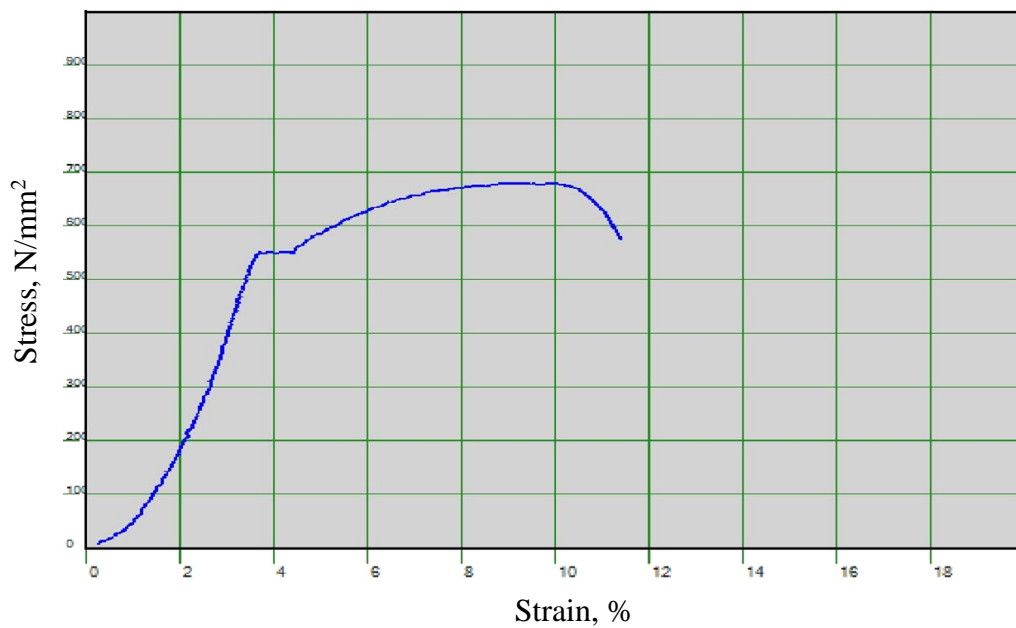
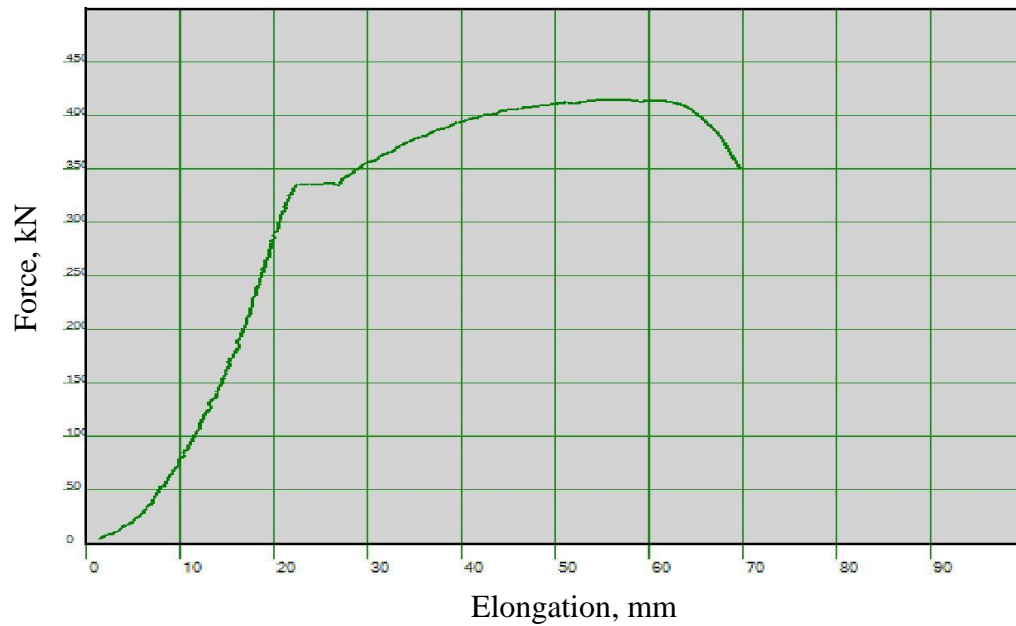
Sample Description		Test Results	
Test Type	Tension/RHN_S2	Peak Load (kN)	211
Test Date	12/Feb/2019_20m	Peak Stress (N/mm ²)	683.589
Sample Type	TMT	Disp. at Peak Load (mm)	58.4
Length (mm)	630	Strain at Peak Stress (%)	9.27
Mass (g)	1526.5	Yield Load (kN)	175.556
Sample Area (mm ²)	308.67	Yield Point Extension (mm)	26.23
		Yield Stress (N/mm ²)	568.759



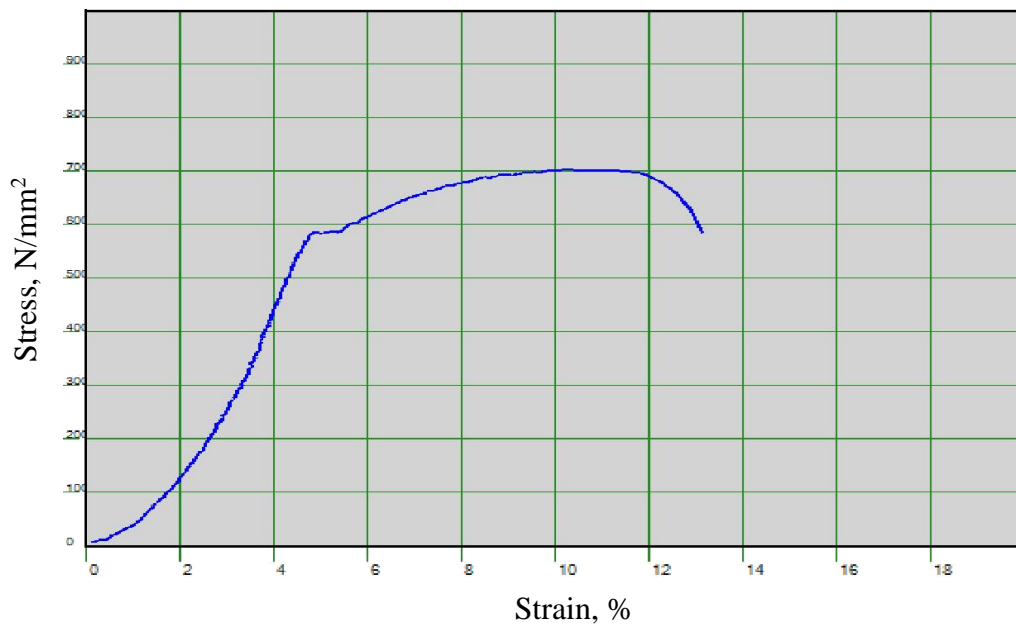
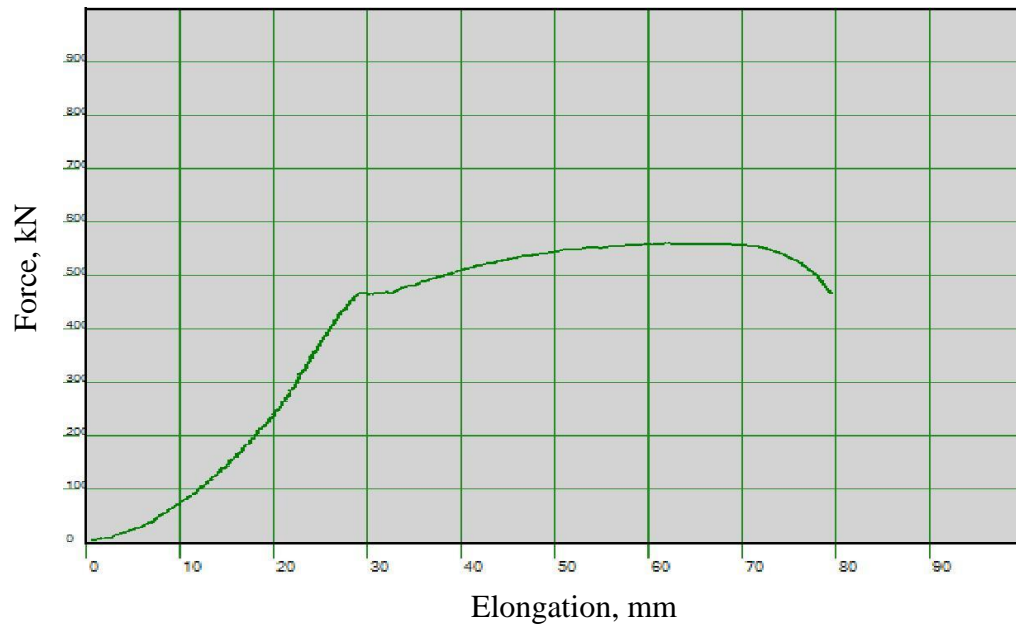
Sample Description		Test Results	
Test Type	Tension/RHN_S2	Peak Load (kN)	331.7
Test Date	12/Feb/2019_25m	Peak Stress (N/mm ²)	684.725
Sample Type	TMT	Disp. at Peak Load (mm)	48.7
Length (mm)	616	Strain at Peak Stress (%)	7.906
Mass (g)	2342.5	Yield Load (kN)	270
Sample Area (mm ²)	484.43	Yield Point Extension (mm)	24.73
		Yield Stress (N/mm ²)	557.358



Sample Description		Test Results	
Test Type	Tension/RHN_S2	Peak Load (kN)	414.4
Test Date	12/Feb/2019_28m	Peak Stress (N/mm ²)	679.524
Sample Type	TMT	Disp. at Peak Load (mm)	57.9
Length (mm)	611	Strain at Peak Stress (%)	9.476
Mass (g)	2925	Yield Load (kN)	334.445
Sample Area (mm ²)	609.84	Yield Point Extension (mm)	26.87
		Yield Stress (N/mm ²)	548.415



Sample Description		Test Results	
Test Type	Tension/RHN_S2	Peak Load (kN)	560.3
Test Date	12/Feb/2019_32m	Peak Stress (N/mm ²)	702.853
Sample Type	TMT	Disp. at Peak Load (mm)	62
Length (mm)	605	Strain at Peak Stress (%)	10.248
Mass (g)	3786	Yield Load (kN)	466.667
Sample Area (mm ²)	797.18	Yield Point Extension (mm)	32.62
		Yield Stress (N/mm ²)	585.398



ANNEX VIII: CALIBRATION CERTIFICATE OF TESTING EQUIPMENTS



NABL/C-0544

HEICO ENGINEERING SERVICES PVT.LTD

SERVICING OF ENGINEERING, SCIENTIFIC & INDUSTRIAL INSTRUMENTS

A-13, NARAINA INDUSTRIAL AREA
 PHASE - II NEW DELHI - 110 028
 PHONE: 011 25893820 (4 Lines)
 Fax: 011-25893152
 Email: service@heico.in

Date: - 07/06/2016	Certificate No:- HEICO/16/0424	Page:- 1	No. of Pages:- 1
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CALIBRATION CERTIFICATE

SRF No. : HEICO/16/03/0344	LOCATION : Delhi
Machine. : AUTO UTM Digital	CUSTOMER (NAME & ADD): M/s Hydraulic & Engineering Instruments A-13, Naraina Industrial Area, Phase-II New Delhi-28
Model No : HLC-591.25	
Sr. No. : H-04289	
Environmental condition : 24°C, RH -34 %	
Calibration Mode. : Compression	
Scale Range. : 0 to 1000 kN	
Certified Range. : 100 to 900 kN	

Master Equipment (Proving Ring)

Details of Force Measuring Instruments used: Instrument Sr. No. PR-089 Capacity : 1000 kN,

Certificate No:- 15090729/D5.05/C-396 Recommended date for the Next Calibration: 14/12/2017

Force F kN	Std.at 23°C	Std.at Room temp 24 °C	Reading of Force Proving Instruments				Diff.	Acc. Error (q)	Rel. Rep. (b)
			Test 1 F1	Test 2 F2	Test 3 F3	Mean F̄			
100	104.0	100.03	100.0	100.2	99.5	99.90	-0.13	-0.13	0.70
200	208.1	200.05	201.0	201.0	200.0	200.67	0.61	0.31	0.50
300	315.2	300.08	300.0	301.0	301.0	300.67	0.59	0.19	0.33
400	417.1	400.11	401.0	400.0	401.0	400.67	0.56	0.14	0.25
500	521.0	500.14	501.0	502.0	501.0	501.33	1.20	0.24	0.20
600	627.0	600.16	600.0	599.0	600.0	599.67	-0.50	-0.08	0.17
700	729.5	700.19	700.0	698.0	698.0	698.67	-1.52	-0.22	0.29
800	832.6	800.22	800.0	800.0	797.0	799.00	-1.22	-0.15	0.38
900	939.1	900.24	901.0	901.0	897.0	899.67	-0.58	-0.06	0.44

Reading on Removal of Force 0

Relative Zero Error % (fo) 0

Relative Resolution (a) = 0.1

Expanded Uncertainty of Measurement at Approximately 95 % Confidence Level = ± 0.60%

This Machine has been verified as per Indian Standard IS-1828 (Part -1) 2005. Results relate only to the items calibrated. Certificates shall not be Reproduced Except in full, without the written approval of M/s. HEICO Engineering Services Pvt. Ltd

Note: - Acc. Error (q) = Relative Accuracy Error
 Rel. Rep. (b) = Relative Repeatability Error

Recommended date for the Next Calibration: 06/06/2017

Calibrated By

Technical Manager
 Mr. H.B. Sahu



Government of Nepal
Ministry of Industry
Nepal Bureau of Standards & Metrology
Scientific Metrology Laboratory



Balaju, Kathmandu

Universal Testing Machine

Calibration Certificate

Issue Date
August 9, 2017
Page 1 of 3

CCFM-235/1005
NBSM
2073/74

Calibrated for: NBSM, Mechanical Testing Laboratory
Balaju, NBSM Premises

Instrument: Universal Testing Machine

Manufacturer: TINIUS OLSEN

Operating type: Electrically Operating System

Dial gauge description:

Maximum load: 60 kN

Resolution: 0.05 kN

Serial No. : 156090

Ram diameter (mm): Not available

Range of calibration: (10 - 40) kN

This calibration certificate documents the traceability to National Standards, which realize the units of measurement according to the International System of Units (SI).

Machine location: Laboratory Room
Balaju, NBSM Premises

Order No.: 2372 dated 2073.09.25

Number of pages of certificate: 3

Date of calibration: June 23, 2017

Recommended date for next calibration: June 22, 2018

The user is obliged to have the object recalibrated at appropriate intervals.

This calibration certificate may not be reproduced other than in full except with the permission of Nepal Bureau of Standards & Metrology (NBSM), Scientific Metrology Laboratory. Calibration certificates without signature and seal are not valid.

Calibrated by

Checked by

Approved by

Bhuwan Dawadi

Tilak K.C.

Santosh Sharma

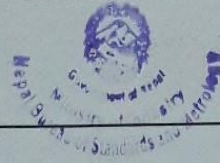
Metrologist

Metrologist

Senior Metrologist

P. O. Box: 985, Ph: +977-1-4350818, 4356672 Fax : +977-1-4350689

Certificate Issue Date: August 9, 2017



Page 2 of 3

CCFM-235/1005

NBSM

2073/74

Calibration Result

Temperature during Calibration: 26.3 °C

Load indicated in dial gauge of UTM machine (kN)	True load (kN)	Correction (kN)	Expanded Uncertainty (kN)
10	10.6	0.6	0.1
20	20.6	0.6	0.1
30	30.7	0.7	0.1
40	40.4	0.4	0.1

Standards and traceability

Serial No.	Manufacturer	Tracability
1155-14-19542/50 kN	ELE, England	Traceable to the Primary Standard of force, National Physical Laboratory, India.

Calibration method:

Calibration of Universal Testing Machine is performed by comparison between the measurement value for the calibration item and a Standard Proving Device as a reference standard.

Calibration procedure:

The calibration procedure is developed according to ISO 7500-1:2004 -Tension/compression testing machines- verification and calibration of the force-measuring system.

Uncertainty of measurement:

Uncertainty of measurement reported is the expanded uncertainty of measurement which result from combined uncertainty by multiplication with the coverage factor $k=2$. Generally the value of the measurand is within the assigned interval of values with a confidence interval of approximately 95%.

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Certificate Issue Date: August 9, 2017



Page 3 of 3

CCFM-235/1005

NBSM

2073/74

Identification:

An identification of calibration mark which labels CCFM-235/1005 has been affixed on calibration item.

Remarks:

1. The correction should be algebraically added to indicated load on dial gauge of machine to get the actual load applied.
2. An interpolation within the calibration range is permitted.

Note: This calibration certificate will not be valid, if

- 1) The machine or display is repaired.
- 2) Calibration Site (Laboratory Room, Balaju, NBSM Premises) is changed.

End of Calibration Certificate.

P. O. Box: 985, Ph: +977-1-4350818, 4356672 Fax : +977-1-4350689

Bhuway

Janki

[Signature]



Balaju, Kathmandu

Universal Testing Machine

CCFM-234/1004

Calibration Certificate

Issue Date
August 9, 2017
Page 1 of 3

NBSM

2073/74

Calibrated for: NBSM, Mechanical Testing Laboratory
Balaju, NBSM Premises

Instrument: Universal Testing Machine

Manufacturer: TINIUS OLSEN

Operating type: Electrically Operating System

Dial gauge description:

Maximum load: 300 kN

Resolution: 0.25 kN

Serial No. : 156090

Ram diameter (mm): Not available

Range of calibration: (50 - 300) kN

This calibration certificate documents the traceability to National Standards, which realize the units of measurement according to the International System of Units (SI).

Machine location: Laboratory Room
Balaju, NBSM Premises

Order No.: 2372 dated 2073.09.25

Number of pages of certificate: 3

Date of calibration: June 23, 2017

Recommended date for next calibration: June 22, 2018

The user is obliged to have the object recalibrated at appropriate intervals.

This calibration certificate may not be reproduced other than in full except with the permission of Nepal Bureau of Standards & Metrology (NBSM), Scientific Metrology Laboratory. Calibration certificates without signature and seal are not valid.

Calibrated by

Checked by

Approved by

Bhuvan Dawadi

Tilak K.C.

Santosh Sharma

Metrologist

Metrologist

Senior Metrologist

Certificate Issue Date: August 9, 2017



Page 2 of 3

CCFM-234/1004

NBSM

2073/74

Calibration Result

Temperature during Calibration: 25.3 °C

Load indicated in dial gauge of UTM machine (kN)	True load (kN)	Correction (kN)	Expanded Uncertainty (kN)
50	47.5	-2.5	0.9
100	96.9	-3.1	0.5
200	196.5	-3.5	1.2
300	296.9	-3.1	0.9

Standards and traceability

Serial No.	Manufacturer	Tracability
1052-9-2034/1000 kN	ELE, England	Traceable to the Primary Standard of force, National Physical Laboratory, India.

Calibration method:

Calibration of Universal Testing Machine is performed by comparison between the measurement value for the calibration item and a Standard Proving Device as a reference standard.

Calibration procedure:

The calibration procedure is developed according to ISO 7500-1:2004 -Tension/compression testing machines- verification and calibration of the force-measuring system.

Uncertainty of measurement:

Uncertainty of measurement reported is the expanded uncertainty of measurement which result from combined uncertainty by multiplication with the coverage factor $k=2$. Generally the value of the measurand is within the assigned interval of values with a confidence interval of approximately 95%.

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Bhawan

Joshi

Singh

Certificate Issue Date: August 9, 2017



Page 3 of 3

CCFM-234/1004

NBSM

2073/74

Identification:

An identification of calibration mark which labels CCFM-234/1004 has been affixed on calibration item.

Remarks:

1. The correction should be algebraically added to indicated load on dial gauge of machine to get the actual load applied.
2. An interpolation within the calibration range is permitted.

Note: This calibration certificate will not be valid, if

- 1) The machine or display is repaired.
- 2) Calibration Site (Laboratory Room, Balaju, NBSM Premises) is changed.

End of Calibration Certificate.

P. O. Box: 985, Ph: +977-1-4350818, 4356672 Fax : +977-1-4350689

A handwritten signature in black ink, appearing to read 'Bhuvan'.

A handwritten signature in black ink, appearing to read 'Anand'.

A handwritten signature in black ink, appearing to read 'S. P.'.



Balaju, Kathmandu

Universal Testing Machine

Calibration Certificate

Issue Date
 August 9, 2017
 Page 1 of 3

CCFM-233/1003
NBSM
2073/74

Calibrated for: NBSM, Mechanical Testing Laboratory
 Balaju, NBSM Premises

Instrument: Universal Testing Machine

Manufacturer: TINIUS OLSEN

Operating type: Electrically Operating System

Dial gauge description:

Maximum load: 600 kN
Resolution: 0.5 kN
Serial No. : 156090
Ram diameter (mm): Not available
Range of calibration: (100 - 500) kN

This calibration certificate documents the traceability to National Standards, which realize the units of measurement according to the International System of Units (SI).

Machine location: Laboratory Room
 Balaju, NBSM Premises

Order No.: 2372 dated 2073.09.25

Number of pages of certificate: 3

Date of calibration: May 16, 2017

Recommended date for next calibration: May 15, 2018

The user is obliged to have the object recalibrated at appropriate intervals.

This calibration certificate may not be reproduced other than in full except with the permission of Nepal Bureau of Standards & Metrology (NBSM), Scientific Metrology Laboratory. Calibration certificates without signature and seal are not valid.

Calibrated by

Checked by

Approved by

Bhuwan Dawadi

Tilak K.C.

Santosh Sharma

Bhuwan Dawadi

Tilak K.C.

Santosh Sharma

Metrologist

Metrologist

Senior Metrologist

Certificate Issue Date: August 9, 2017



Page 2 of 3

CCFM-233/1003

NBSM

2073/74

Calibration Result

Temperature during Calibration: 25.2 °C

Load indicated in dial gauge of UTM machine (kN)	True load (kN)	Correction (kN)	Expanded Uncertainty (kN)
100	101.1	1.1	0.8
200	201.5	1.5	0.8
300	304.2	4.2	1.2
400	405.0	5.0	1.2
500	508.4	8.4	2.0

Standards and traceability

Serial No.	Manufacturer	Tracability
1052-9-2034/1000 kN	ELE, England	Traceable to the Primary Standard of force, National Physical Laboratory, India.

Calibration method:

Calibration of Universal Testing Machine is performed by comparison between the measurement value for the calibration item and a Standard Proving Device as a reference standard.

Calibration procedure:

The calibration procedure is developed according to ISO 7500-1:2004 -Tension/compression testing machines- verification and calibration of the force-measuring system.

Uncertainty of measurement:

Uncertainty of measurement reported is the expanded uncertainty of measurement which result from combined uncertainty by multiplication with the coverage factor $k=2$. Generally the value of the measurand is within the assigned interval of values with a confidence interval of approximately 95%.

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Bhuway

Janak

[Signature]

Certificate Issue Date: August 9, 2017



CCFM-233/1003

NBSM

Page 3 of 3

2073/74

Identification:

An identification of calibration mark which labels CCFM-233/1003 has been affixed on calibration item.

Remarks:

1. The correction should be algebraically added to indicated load on dial gauge of machine to get the actual load applied.
2. An interpolation within the calibration range is permitted.

Note: This calibration certificate will not be valid, if

- 1) The machine or display is repaired.
- 2) Calibration Site (Laboratory Room, Balaju, NBSM Premises) is changed.

End of Calibration Certificate.

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Government of Nepal
Ministry of Industry
Nepal Bureau of Standards & Metrology
Scientific Metrology Laboratory
Length Laboratory



Balaju, Kathmandu

Calibration Certificate of Vernier Caliper	Calibration Mark Page 1 of page 1	CCLMI - 44/253
		NBSM
		2071/72

Calibrated for : *Mechanical Laboratory*
NBSM Premesis, Balaju, Kathmandu

Description of calibration object:

Calibration object: *Vernier Caliper*
Made by: *Mitutoyo*
Serial no.: *N/A*
Range: *(0 - 150) mm*
Resolution: *0.02 mm*

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).

Order no.: *2504 dated 2070.10.21*

Date of calibration: *January 18, 2015*

Recommended date for next calibration: *January 17, 2016*

Temperature during calibration: *14.8 °C*

The user is obliged to have the object recalibrated at appropriate intervals.

Results of Measurement

S. No.	Test Length (mm)	Average instrument reading (mm)	Correction (mm)
1	1.02	1.02	0.00
2	1.50	1.50	0.00
3	5.00	5.00	0.00
4	10.00	10.00	0.00
5	50.00	50.00	0.00
6	75.00	75.00	0.00
7	100.00	100.00	0.00
8	150.00	150.00	0.00

The Vernier Caliper is calibrated against the standard slip gauges of Length Laboratory, Nepal Bureau of Standard and Metrology (NBSM) traceable to National Physical Laboratory (NPL) India

Remark:

The correction has to be algebraically added to the instrument reading to get actual reading.

This calibration certificate may not be reproduced other than in full except with the permission of NBSM Scientific metrology laboratory. calibration Certificates without signature and seal are not valid.

Issued date	Calibrated by	Checked by	Approved by
January 20, 2015			
	Arjun Dhakal Metrologist	Pabitra Koirala Metrologist	Rakesh Kumar Jha Director

End of calibration Certificate

P. O. Box: 985, Ph: +977-1-4356672, 4350818 ; Fax : +977-1-4350689

ANNEX IX: PHOTOGRAPHS DURING THE TEST AT NBSM



Figure IX.1 Reference samples stored at NBSM



Figure IX.2 Sample preparation for tensile test



Figure IX.3 Bend and Re-bend Test



Figure IX.4 Tensile Testing