Chapter 1

INTRODUCTION

1.1 General

For almost 100 years, construction practices in building of concrete structures have forced on the use of steel reinforcement to transfer tension and shear forces. Lap splicing has become the traditional method of connecting the steel reinforcing bars; largely due to the misconcept the lap splicing is “no cost” splicing.

Lap splicing requires the overlapping of two parallel bars. The overlap load transfer mechanism takes advantage of the bond between the steel and the concrete to transfer the load. The load in one bar is transferred to the concrete, and then from concrete to the ongoing bar. The bond between steel and concrete plays very important role in this case of lap splicing of the reinforcing bars.

But now scenario is completely change. Nowadays due to the rapid urbanization and increasing land cost, high-rise buildings are more in demand. In the context of our country Nepal, 15-20 stories building will be common after 10 to 15 years. Continuing research, more demanding designs in concrete constructions, new materials, hybrid concrete/structure steel designs and other changes in the construction industries are calling for use of alterative to lap splicing. From the stand point of functions, lap perform well on bar size 20mm and 25mm of 40KSI yield steel and 3000 lb concrete, with a structure of 15 stories considered a highrise. Today building taller than 15 stories are increasingly common. A “high-rise” of reinforced concrete in Kuala Lampur, Malaysia recently topped 100 stories, and at least a half dozen other 85 plus story building are under construction or planned.

The use of high strength concrete which is more prone to splitting also is on the increase. Compounding this problem, calculation within the ACI code results in shorter lap length with high strength concrete.

Recent presidential orders for Federal building in US also are increasing the focus on structural seismic safety. According to Executive Order 12941, signed in 1996 each agency that owns or leases the buildings for federal use must ensure that the building is designed and built in according with proper sesmic design and costruction standards.The order mandates the consideration of seismic safety in any building occupied by Federal agent.

1.2 Problems and issues:

In the context of Nepal conventional lap splicing is frequently used in every construction work. But the future construction work will be very much different from now as due the the more urbanization and high land prices the high rise building are now more in demand. 15 stories building is recently constructed in the country and half dozen other 15 plus buildings are planned to construct. So the new technique of construction is needed very much in a short time for the country as the world is now facing very much problems from the conventional lap splicing technique.

1.3 Lap Splicing Problems:

Over the years, many structural engineers, architects and specifies have noted that lap splicing have few advantages and may disadvantages. ACI R21.3.2.3 states that lap splices are not considered reliable under conditions of cyclic loading into the elastic range. Further, there is a question as to the effectiveness of the laps with larger bars: 25mm, 28mm, 32mm and 36mm.There are major structural elements in the frame of reinforced concrete structures, and any question regarding their efficacy is cause of concern.

Over the years, to counter these concerns, the lap lengths in the ACI 318 Building code have become longer and longer. ACI 12.14.2.1 has prohibited the use of lap splices in the bar size 43mm and 57mm. Laps are also prohibited on bar sizes in tension tie members (ACI 12.15.5) and within joints and location of flexure yielding (ACI 21.3.2.3)

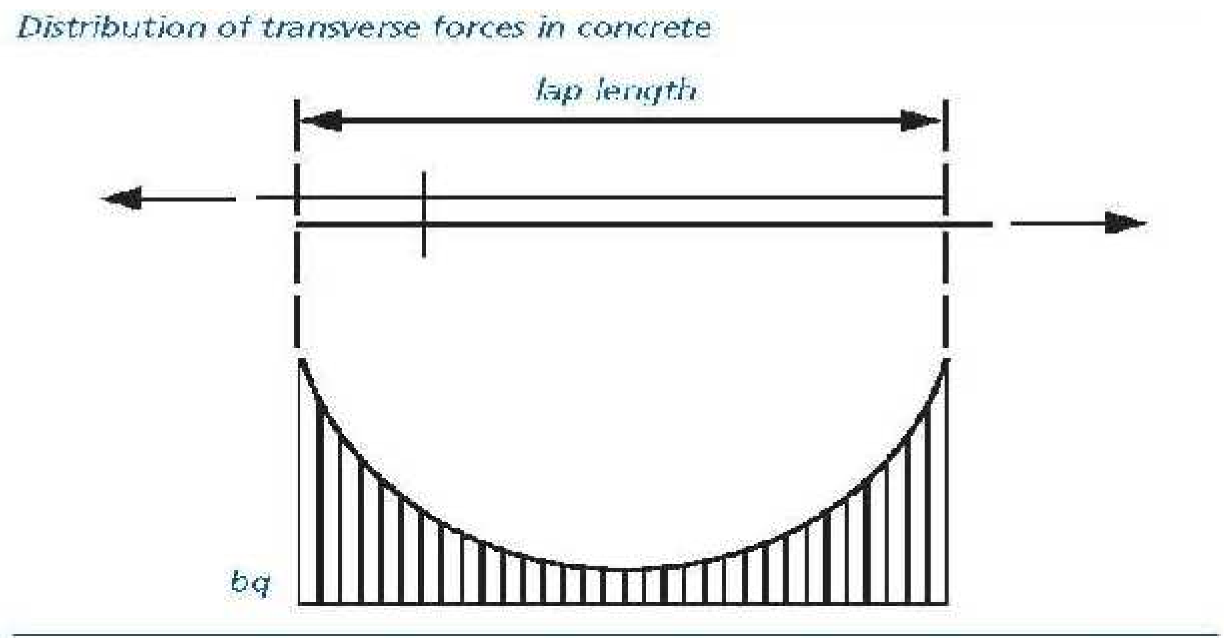


Fig 1: Distribution of transverse forces in concrete

Concern about the lap splicing go to the vary principles that are the basis for lap splicing. Lap splicing requires concrete to take tension and shear loads, though concrete is notoriously poor in handling tension and shear. As a result of load transfer, the steel bar may be in axial tension or in axial compression. The above figure shows the distribution of tensile stress in the concrete normal to the axis of the bars. The overlaps transfer method generates additional forces in the concrete which tends to push the bar apart, so concrete cover must be strong enough to overcome this “brusting” force. Brusting force can cause spalling of concrete cover and slip failure. Because of brusting force for large size reinforcing bars additional transverse reinforcement is required by most design codes.

To design the correctly engineered lap splices, certain parameters must be considered (ACI 12.2) .These includes:

1. **Grade of Steel:** the higher the yield stress the greater the lap length.
2. **Surface condition of the bar:** epoxy coated bars required upto 50% longer lap than black bars.
3. **Size of bars:** the larger the bar, the longer the lap.

4. **Grade of concrete:** lower the concrete strength, longer the lap required.
5. **Location of splice:** efficiency is dependent on bar location, position in the structural member, edge condition and spacing.
6. **Design Load:** the lap length required in the bar for tension is much longer than for the same size bars in compression load. A lap design for compression load will not perform as a full tension splice. In this even of unanticipated forces to a structure, lap splice may fail.

As a result, some rules must be followed for the design and execution of lap splices:

1. Lap splices must be located at the point of minimum stress.
2. Only a limited number must be joined in one section.
3. Additional transverse reinforcement is necessary for larger bar size. In the area of overlap connections (lap zones), a double number of bars are present which increase rebar congestion and can restrict the flow and proper distribution of larger aggregates, causing difficulties in the efficient vibration of the concrete. This “strainer effect” is one of the major causes for forming rock patches and contributes the poor quality concrete. While the ACI Codes stipulates a steel to concrete ratio under 8%, it is difficult to follow this regulation and achieve a balanced design because of addition rebars in the lap zone as shown in the figure below.

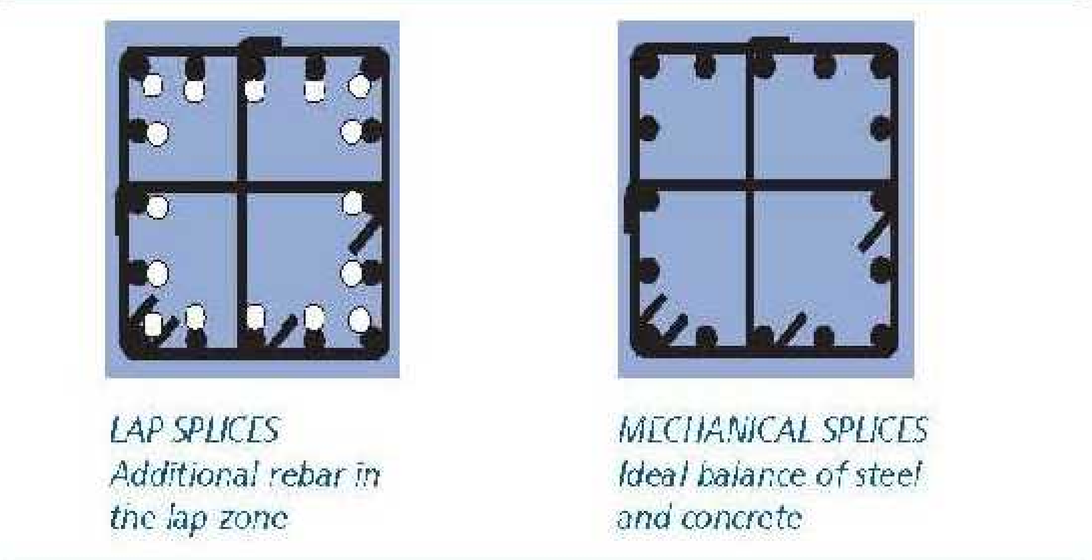


Figure 2: Comparison between conventional lap splicing and mechanical splicing in a lap zone.

Because lap splices develop their strength from concrete cover, deterioration of concrete will inevitably leads to splice failure. One disadvantage of lap splices is that they offer poor cyclic performance in the inelastic range. In Snow Belt and coastal regions, corrosion of rebars can lead to delamination of spalling of the concrete cover. Without proper cover the lap splice becomes ineffective in bond the load path broken.

Loss of load path continuity can be tragic. A classic example is the Alfred P.Murrah Federal Building in Oklahoma City, which is destroyed by bomb in 1995. This building was well designed and built to standard requirements. Rebars were properly placed; concrete of correct strength etc.but a catastrophic failure of the structure results from the removal of one column. In a reinforced concrete structure, there was no requirement for making bottom bars continuous from span to span. If a support is removed, the girder fails. The progressive collapse occurred due to lack of continuity of reinforcing steel, the lapped spliced failed. According to FEMA investigators, “65% to 85%” of the collapse might have been avoided if continuity of reinforcement can be achieved either through the use of one continuous length of rebars or through mechanical means.

Lap splicing; then, can be considered structurally less reliable and design-constrictive, with many “hidden” costs.

1.4 Need of the study:

As it is already discussed that due to the rapid urbanization, new heavy structures have been constructed and conventional lap splices have many limitations and disadvantages in terms of strength and reliability of structure, new techniques must be introduced or adapted for our future construction. One alternative to lapping is to splice bar by welding. But welding is generally more expensive and is reliable only if weldability of the rebar is insured by supplementary specifications for the chemistry of the rebar steel. Thus only means remains for the alternative of splices is the use of mechanical connectors.

1.5 Objectives of the study:

1.5.1 Overall objective

The main aim of carrying out this research work is to understand the behavior of mechanical splicing. These results by capturing the true behavior of the mechanical couplers will lead to some valuable information and guidelines for the future construction work.

1.5.2 Specific objective

a. To identify the performance of mechanical splicing –
    I. In direct tension and compression.
    II. For the larger ø bars i.e. 16mm, 25mm and 32mm.

b. To find out the cost effectiveness in comparison with the conventional lapping procedure and compare the result with manufactures specification.

1.6 Methodology:

To achieve the objective of the research work, the following procedures were adopted:

1) Survey and review of various literatures those are available to the related work.

2) Selection of suitable type of mechanical connector (Trappered threaded connector) among various type of connector available.

3) Establish the various parameters such as length of coupler bar, its diameter, area of bar engagement, no of rebar thread and weight of coupler from manufactures specification.

4) Fabricate the couplers as per the parameter selection.

5) Lab test on three samples each as continuous bar, lap spliced bars and mechanically spliced bars in direct tension and compression.

6) Larger dia bars restricted by the ACI code for lap splicing is also taken into consideration. For the test 16mm dia bar, 25mm, and 32mm are taken into consideration.

7) The results obtained from the lab are then observed and compared to each other in the form of stress – strain diagrams.

1.7 Organization of thesis:

The thesis is organized in five chapters.

Chapter 1 introduces subject matter in this thesis, background and present status, lap splicing problems and need of the study. Objective of the study and methodology are also discussed in this chapter.

Chapter 2 deals with literature reviews regarding the mechanism behind the couplers, its’ types, manufactures specifications, past tests, limitation of conventional lapping and welding.

Chapter 3 includes detail experimental investigation, which consists of material properties, preparation of specimens, fabrication of couplers, experimental set-up and testing of materials and specimens.

Chapter 4 deals with the discussion on experimental results

Chapter 5 includes summary of the study with conclusion and further recommendation.

Chapter 2

LITERATURE REVIEW

Mechanical splices are the mechanical connection between two pieces of reinforcing steel that enable the bars to behave in a manner similar to continuous lengths of reinforcing steel bars. Mechanical splices join rebar end to end, providing many advantages of a continuous piece of rebar. Years ago, arc welding was the only method of achieving continuity. Today, a myriad of mechanical splices are available to ensure that a precise, reliable connection can be quickly and easily made.

Mechanical splices are more reliable than lap splices because they do not depend on concrete for load transfer. Further they are stronger than lap splices: ACI requirement for mechanical splices are at least 25% higher than typical design strengths for lap splices. Mechanical splices provide superior strength during load transfer. Superior cyclic performance and great structural integrity during manmade, seismic or other natural events are other advantages of mechanical splices.

From the structural prospective, the most important benefit of using mechanical splices is to ensure load path continuity of the structural reinforcement independent of the condition or existence of the concrete. Additionally, mechanical splices reduce congestion of the reinforcing concrete by eliminating laps.

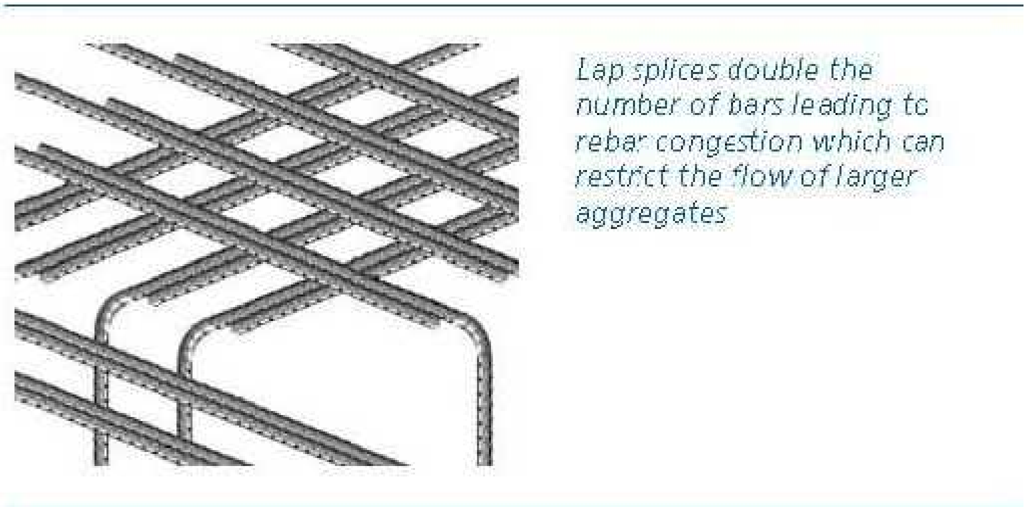
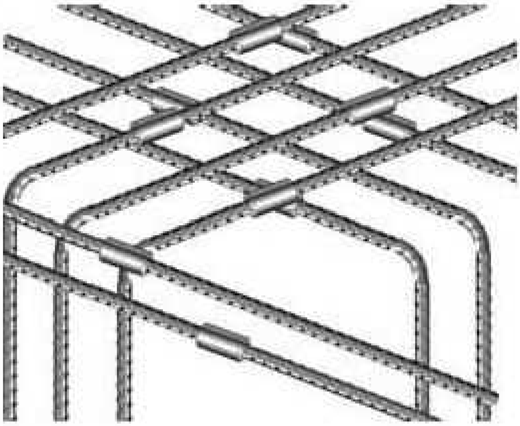


Figure 3: Rebar congestion in lap splicing.



Mechanical couplers reduce rebar congestion and improve concrete consolidation

Fig 4: Reduction of rebar congestion by using mechanical couplers

Laps doubles the steel/concrete ratio and creates problems while placing the bar and during concrete consolidation. Elimination of laps also frees space for post tensioning operations.

For the design perspective, mechanical splices can be relied upon to improve steel to concrete ratios, which assist in delivering a consistent ratio under 8% **(Study conducted by ERICO Concrete Reinforcement Products.)** When using laps, working with smaller diameter reinforcing bars may required the use of large column dimensions to accommodate the great quantity of bars. Using mechanical splices allows the option of using larger diameter rebar in a smaller column, while minimizing congestion. Reduce column size results in more effective optimum use of floor space- and extremely beneficial economic and design consideration as shown in figure below:

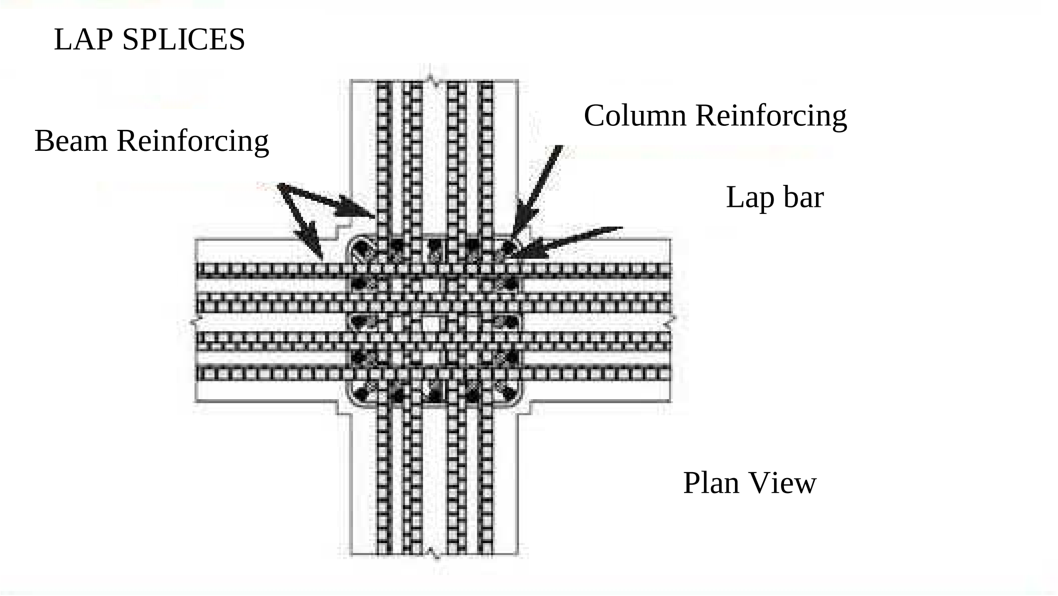


Fig 5: Bar congestion in joint between beam and column

Efforts to evaluate the comparative costs of using lap splicing and mechanical splices in concrete construction shows that the reputation of mechanical splices for adding substantial cost to a construction budget is unfounded. A recent study conducted by Cagley and Associates of two structures shows that the additional cost of mechanical splicing, with integrated as part of the original design, is less than 0.2 percent. Further, only column steel was considered. According to authors, had beam steel been mechanically spliced and included in the comparison, the comparative cost would have been equal.

Mechanical splices do away with the tedious calculation needed to determine proper lap lengths, and their potential errors. Because mechanical splices do not overlap, less rebar is used, reducing materials cost. Mechanical splices also are fast to install with no specialized labors. Easier placement of the bars saves valuable crane time, and helps to keep labor costs to a minimum while maintaining or accelerating project schedules.

According to “The hand book on concrete reinforcement and detailing “, published by the bureau of Indian standard, there are following types of mechanical connectors:

Sleeve splicing: If correctly used, sleeve connections may transmit the total compressive or tensile stress. In general, the use of these sleeves is governed by various conditions laid down in the agreement for the method or , in the absence of recommendations, by preliminary testing.

During assembly, particular care shall be taken to ensure that the lengths introduced into the sleeve are sufficient.

These lengths should be marked before hand on the ends of the bars to be spliced except when a visual check on penetration is possible.

A) Threaded couplers:

In order to prevent any decrease in the end sections of the bar as a result of threading (with V-form or round threads), they can be:

a. Upset.

b. For long units, fitted with larger section threaded ends by flash welding; or

c. Fitted with a threaded sleeve by crimping.

Another solution consists of threading the ends but only taking into consideration the nominal section of the threaded end that is, reducing the permissible stress in the reinforcement.

The ends of the sleeve shall be slightly reduced in section in order to prevent overstressing of the first few threads.

There are, at present, reinforcing bars with oblique, discontinuous, spiral ribs, allowing splicing with a special sleeve with internal threads.

This same process is used to splice prestressing bars, and in order to prevent confusion between reinforcing bars and prestressing stress, the direction of threading is reversed.

Two lock nuts, tightened on each side of the sleeve into which the reinforcing bars are introduced to the same depth, prevent any accidental unscrewing due to slack in the threads (splices not under tension). The nuts are tightened with a torque wrench.

This device is also used for splicing prefabricated elements.

These joints are generally 100 percent efficient under both tension and compression.

To decrease the in-situ operations, one of the ends is generally fitted with its sleeve in advance and the other bar to be joined with the sleeve should remain maneuverable until the splice has been made.

B) Coupling with a crimped sleeve:

Crimped sleeves constitute a method of splicing limited to relatively large diameter deformed reinforcing bars. It consists of the introduction of the bars to be spliced into a sleeve which is crimped by means of a hydraulic crimping tool onto the ribbed bars in order to fill the voids between them and the inner surface of the sleeve. The ribs on the bar penetrate into the relatively softer steel of the sleeve and the ribs work in shear.

During crimping the sleeve lengthens, and the other reinforcing bar to be spliced should be displaceable at this moment. The size of the crimping device requires a bar interspacing of at least 10 cm.

Splicing by crimping is also possible with reinforcing bars of differing diameter. The same method also enables threaded steel rods to be spliced to reinforcing bars, using high strength threaded bolts.

C) Coupling with injected sleeves:

These couplings are a special case of sleeve splicing; the stresses are distributed by the shear strength of the product injected between the ends of the bars to be sleeve spliced.

With the ‘Thermit’ sleeve the space between the deformed bars and the sleeve, whose internal surface is also ribbed, is filled with a special molten metal. This molten metal is prepared in a crucible, which is in communication with the sleeve, by igniting a mixture consisting mainly the iron oxide and aluminum powder. The strength of the sleeve may be increased by using a large sleeve diameter.

The sleeve is shorter but wider than that used in the crimping method.

The bars are not in contact.

The splice may be made in any direction as long as space allows the crucible to be put into place.

Similar method is the injection of grout or an epoxy resin between the sleeve and the bars. The length of the sleeve is necessarily greater.

D) Butt splices:

For this purpose open flange sleeves made from steel strip can be used. They are tightened onto the bars by the introduction of a flat tapered wedge.

The end sections, in contact within the device shall be perfectly at right angles to the axis of the spliced bars.

Another method involves the use of 4 small diameter ribbed bars which are tightened, using pliers, with 3 ring-clamps. The advantage of this method, in comparison to the previous one, is the fact that it allows a portion of the tensile stress to be taken up.

For bars with ribs in the form of a thread, a butt splice may be made with a sleeve, but with greater facility.

There are also sleeves consisting of a metallic cylinder, the internal diameter of which fits the bars to be spliced. This sleeve is fixed to one of the reinforcing bars by a few welding points: a hole at the center of the sleeve enables one to check that there is contact between the bars. This economical method of splicing, which is easy to apply, can only transmit compressive stresses.

According to Building Code Requirements to Structural Concrete (ACI 318-95) lap splices shall not be used for bars lager than 36mm. Bars spliced by noncontact lap splices in flexural members shall not be spaced transversely farther apart than one-fifth the required lap splice length, nor 6 inch.

Welded splices and other mechanical connections are allowed. A full mechanical connection shall develop in tension or compression, as required, at least 125 percent of specified strength f_y of the bar. Welded splices and mechanical connections not meeting the requirement are allowed only for the 16mm dia bars and smaller.

Splices of deformed bars and deformed wire in tension

Minimum length of lap for tension lap splices shall be as required for Class A or B splice, but not less than 12 in., where**:**

Class A splice**………………………………………** 1.0 l_d

Class B splice……………………………………..1.3 l_d.

Where l_d is the tensile development length for the specified yield strength f_y.

Lap splices of deformed bars and deformed wire in tension shall be Class B splices except that Class A splices are allowed when: (a) the area of reinforcement provided is at least twice that required by analysis over the entire length of the splice, and (b) one-half or less of the total reinforcement is spliced within the required lap length.

Welded splices or mechanical connections used where area of reinforcement provided is less than twice that required by analysis shall meet requirements of 12.14.3.3 or 12.14.3.4

Welded splices and mechanical connections not meeting the requirements of 12.14.3.3 of 12.14.3.4 are allowed for no.5 bars and smaller when the area of reinforcement provided is at least twice the required by analysis, and the following requirements are met:

Splices shall be staggered at least 24 in. and in such manner as to develop at every section at least twice the calculated tensile force at that section but not less than 20,000 psi for total area of reinforcement provided.

In computing tensile forces developed at each section, rate the spliced reinforcement at the specified splice strength. Unspliced reinforcement shall be rated at that fraction of fy defined by the ratio of the shorter actual development length to ld required to develop the specified yield strength fy.

Splices in “tie members” shall be made with a full welded splice or full mechanical connection in accordance with 12.14.3.3 or 12.14.3.4 and splices in adjacent bars shall be staggered at least 30 in.

Splices of deformed bars in compression.

Compression lap splice length shall be 0.00005fydb, for fy of 60000 psi or less or (0.0009 fy-24) db for fy greater than 60000 psi, but not less than 12 in. For fc’ less than 3000 psi, length of lap shall be increased by one-third.

When bars of different size are lap spliced in compression, splice length shall be the larger of development length of larger bar, or splice length of smaller bar. Lap splices of No. 14 and No. 18 bars to No.11 and smaller bars shall be permitted.

According to the hand book of concrete reinforcement and detailing, the conventional lapping has following requirements:

Diameter of bars for lap splicing: Lap spices shall not be used fro bars larger than 36mm. If lapping has to be done additional spirals should be provided around the

Staggering of lap splices: Lap splices shall be considered as staggered if the centre to centre distance of the spliced is not less than 1.3 times the lap length.

Lap length in tension: Lap length including anchorage value of hooks in flexural tension shall be L_d or 30 Φ whichever is greater and for direct tension 2 L_d or 30 Φ whichever is greater. The straight length of the lap shall not be less than 15Φ or 200mm, whichever is greater.

Lap length in compression: The lap length in compression shall be equal to the development length but not less than 24Φ.

Bars of different dia: When bars of two different diameters are to be spliced, the lap length shall be calculated on the basis of the smaller bar.

Development length (L_d):

Table I: Development length for various grade concrete

Fy(N/mm2)	Tension bars		Compression bars	
	M20	M25	M20	M25
250	46ø	39ø	37ø	31ø
415	47ø	40ø	38ø	32ø
500	58ø	49ø	46ø	39ø

Knowledge of the various properties of steel is a requirement if one is to make intelligent choices and decisions in the selection of particular members. As the base metal used in the coupler is also the steel, the mechanical properties of it are also important before used it in the composition with concrete.

The mechanical properties of the steel depends on:

a. Chemical composition
b. Rolling method
c. Heat and other treatments and
d. Stress history

Important relevant properties of the structural steels are:

1. Ultimate strength (also called tensile strength)
2. Yield or proof stress
3. Ductility
4. Toughness
5. Weldibility
6. Corrosive resistance
7. Mechainabilty

The first four are associated with mechanical properties while the last three are related to fabrication and durability of the material.

The test conducted by the LENTON coupler manufacturers shows that the mechanical splicing give far more good results both in terms of strength and durability.

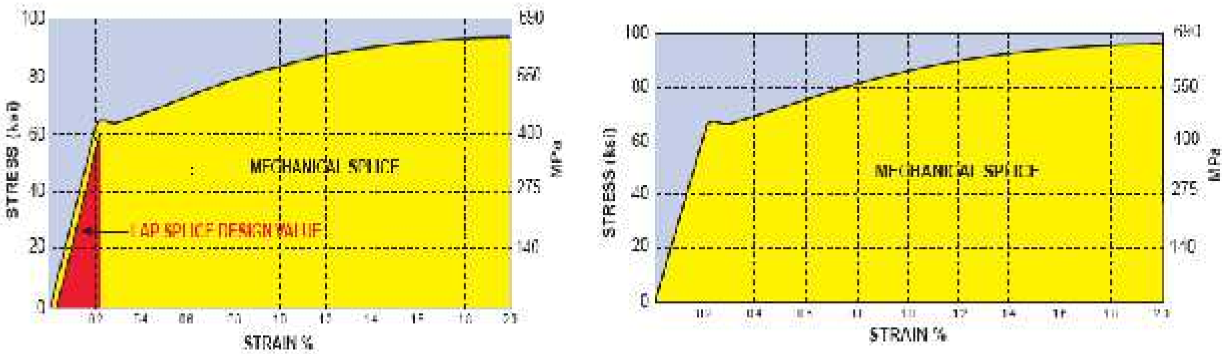
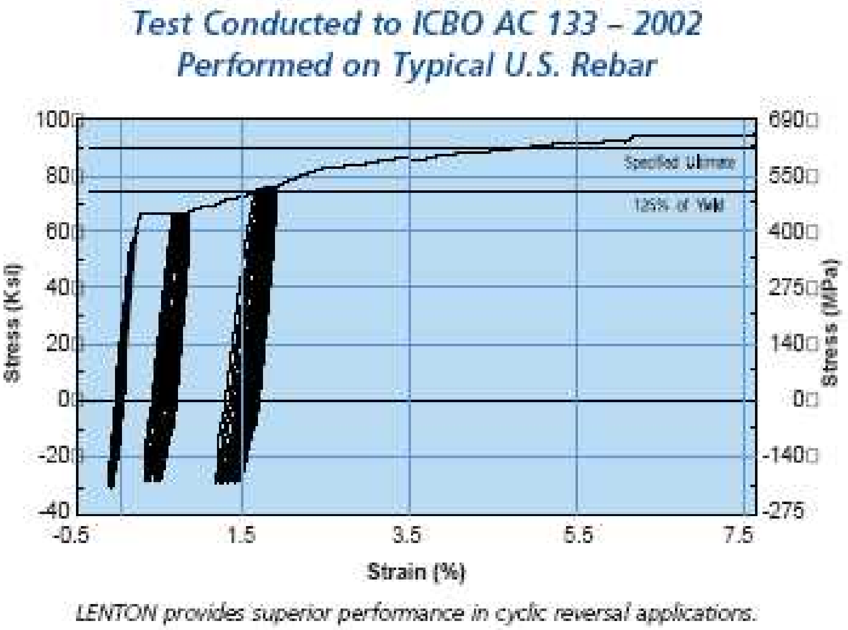


Fig 6: Stress-Strain diagram for Lap splice Vs mechanical splice

The result shows that the mechanical splicing provides significantly high strength by design than lap splices.



Test Conducted to ICBO AC 133 – 2002
Performed on Typical U.S. Rebar

LENTON provides superior performance in cyclic reversal applications.

Fig 7: Cyclic reversal performance of mechanical splice

The above graph shows that the mechanical splice provides superior performance in cyclic reversal application.

Chapter 3

EXPERIMENTAL INVESTIGATION

The preparation of materials and specimens, tests of the materials, test set-up and loading methods are discussed in this chapter. The observation made during the testing are recorded and presented. The results of the experiments are discussed in chapter 4.

3.1 Material collection and properties:

The materials used in this thesis work are Reinforcement bars of ø 16mm, 25mm and 32mm. Couplers of various grade are used whose grade are mentioned below.

Table A: Grade of coupler and reinforcing bars

S.N.	Description	Grade of steel
1	16mm ø Bar	Fe 500
2	25mm ø Bar	Fe 500
3	32mm ø Bar	Fe 500
4	Coupler used in 16mm ø bar	Fe 500
5	Coupler used in 25mm ø bar	Fe 370
6	Coupler used in 32mm ø bar	Fe 500

3.2 Preparation of specimens

3.2.1 Tensile test

Three specimens each of length 500mm is prepared for 16mm, 25mm and 32mm ø bar and corresponding couplers. For lap splicing, specimens were prepared with different lap length each of 100mm, 200mm and 300mm for all three different ø of bars. For tensile test total samples tested are mentioned below:

Table B: Indexing of samples for tensile test

S.N.	Description	No. of samples	Element ID
1	16mm ø Bars	3.00	ST11,ST12,ST13
2	25mm ø Bars	3.00	ST21,ST22, ST23
3	32mm ø Bars	3.00	ST31,ST32,ST33
4	Coupler used in 16mm ø bars	6.00	CT11,CT12,CT13,CT14,CT15,CT16
5	Coupler used in 25mm ø bars	5.00	CT21,CT22,CT23,CT24,CT25
6	Coupler used in 32mm ø bars	5.00	CT31,CT32,CT33,CT34,CT35
7	100mm lapping in 16mm ø bars	2.00	LT111,LT112
8	200mm lapping in 16mm ø bars	2.00	LT121, LT122
9	300mm lapping in 16mm ø bars	2.00	LT131, LT132
10	100mm lapping in 25mm ø bars	2.00	LT211, LT212
11	200mm lapping in 25mm ø bars	2.00	LT221,LT222
12	300mm lapping in 25mm ø bars	1.00	LT231
13	100mm lapping in 32mm ø bars	1.00	LT311
14	200mm lapping in 32mm ø bars	1.00	LT321
15	300mm lapping in 32mm ø bars	1.00	LT331

3.2.2 Compression Test:

Table C: Indexing of samples for compression test

S.N.	Description	No. of samples	Element ID
1	16mm ø Bars	3.00	SC11,SC12,SC13
2	25mm ø Bars	3.00	SC21,SC22, SC23
3	32mm ø Bars	3.00	SC31,SC32,SC33
4	Coupler used in 16mm ø bars	3.00	CC11,CC12,CC13
5	Coupler used in 25mm ø bars	5.00	CC21,CC22,CC23,CC24,CC25

6	Coupler used in 32mm ø bars	3.00	CC31,CC32,CC33
7	100mm lapping in 16mm ø bars	2.00	LC111,LC112
8	200mm lapping in 16mm ø bars	3.00	LC121, LC122,LC123
9	300mm lapping in 16mm ø bars	2.00	LC131, LC132
10	100mm lapping in 25mm ø bars	2.00	LC211, LC212
11	200mm lapping in 25mm ø bars	2.00	LC221,LC222
12	300mm lapping in 25mm ø bars	2.00	LC231,LC232
13	100mm lapping in 32mm ø bars	1.00	LC311
14	200mm lapping in 32mm ø bars	2.00	LC321,LC322
15	300mm lapping in 32mm ø bars	2.00	LC331,LC332

3.3 Fabrication of coupler:

The couplers are fabricated in workshop as per the manufacture’s specification. The dimensions of fabricated couplers are mentioned below:

Table D: Manufacturer’s specifications for couplers

S.N.	Rebar size (mm)	Diameter (mm)	Length (mm)	No of rebar threads	Weight (Kg)
1	16	25	52	10 to 12	0.13
3	25	36	85	13 to 16	0.40
5	32	45	105	17 to 20	0.80

3.4 Testing procedure:

The testing was done in UTM machine to determine the tensile and compressive strength of rebars of ø16mm, 25mm and 32mm, corresponding couplers used in the rebars and the strength of the lap splicing in the lap length of 100mm, 200mm and 300mm. The binding wires are kept at the spacing of 1cm c/c. For both tension and compression the length of specimen are taken as 500mm.The Load vs. deflection graph is given by the UTM machine. The graph is scaled by testing 15 different samples of various ø bars and horizontal and vertical scales are fixed. The horizontal scale is found to be .37mm per three unit and vertical scale is found to be 1530N per three units. Then the analysis was done and stress-strain curve is plotted.

3.5 Mobilization of equipment, machines and apparatus:

Experimental setup and their mobilization have been done before hand to start the relevant test.

Chapter 4

EXPERIMENTAL RESULTS AND DESCUSSION

4.1 General

The experimental results of the study are discussed in this chapter.

4.2 Tensile test of rebars:

The results of the tensile test of rebars are shown in Table 28. If a comparison is done between the results of the tension tests (Table 28) and the requirements of ISO or ASTM (Table 41), it can be seen that the materials fully confirm to these requirements (Table 42).

4.3 Tensile test of couplers:

The results of the tensile test of couplers are shown in Table 29. If a comparison is done between the results of the tension test (Table 29) and the requirements of ISO or ASTM (Table 41), it can be seen that the couplers are less effective. (Table43). It is see n that for the coupler used in 25mm ø bars the result is satisfactory, but only the ratio is found to be in the range but the values of yield and tensile strength are found to be almost half as shown in Table 26.

4.4 Comparison of rebars and couplers in tension in terms of strength:

The results are shown in Table 25, Table 26 and Table 27. If a comparison is done between the results, it is found that for 16mm and 32mm ø bars couplers give the satisfactory result as the strength up to yielding is found to be same or even better and the ultimate strength of the coupler is found to be more than 80% of the strength given by the rebar. However for 25mmø bar, the coupler found to be very less effective which is due to the fact that the grade of the steel used in the fabrication of coupler for 25mmø bar is of low grade than that of the solid rebar.

4.5 Comparison of rebars and couplers in tension in terms of durability:

From the Table 44, it is seen that the strain energy absorbed by the couplers are far lower than that of the rebars. So for the durability consideration, the couplers are not effective as compare to the rebars.

4.6 Compression test on rebars:

From the Table 30, 31, and 32, it is seen that the compressive strength of the rebars increase as the ø of the bar increases and the ratio of the yield and tensile strength is found to be in range. However the specified value for the rebar is not able to achieve.

4.7 Compression test on couplers:

The result of compressive test on couplers is given in the Table 30, 31 and 32. From the table it is seen that the coupler shows the same nature as that shown by the rebars as the compressive strength of couplers are also increase with increase in diameter of the bars. The ratio of the yield and tensile strength is found to be in range.

4.8 Comparison of rebars and the couplers in compression in terms of strength:

The result is shown in the Table 30, 31 and 32. It is clearly seen that the coupler give the better performance in compression as the yield strength and ultimate strength of the couplers are over 90% or even better in comparison with the solid rebars.

4.9 Comparison of rebars and the couplers in compression in terms of durability:

From the Table 45, it is seen that the strain energy absorbed by the coupler is better than that of the rebars. So for the durability consideration, the couplers are very effective. Even the lower grade coupler gives the better performance.

4.10 Tensile strength of rebars in different lap length:

The comparative result is shown in chart 41, 42 and 43, 44,45 and 46.By the observation it is found that for the larger dia of bar as the lap length increases the strength also increase. From this we can conclude that to achieve the required yield or ultimate load as given by the rebars the lap length much be increase more than that specified by the codes. However the smaller dia bars can have better strength even in the short lap length.

4.11 Compressive strength of rebars in various lap length:

The comparative result is shown in chart 47, 48 and 49, 50,51 and 52.By the observation it is found that for the larger dia of bar as the lap length increases the strength also increase. From this we can conclude that to achieve the required yield or ultimate load as given by the rebars the lap length much be increase more than that specified by the codes. However the smaller dia bars can have better strength even in the short lap length same as in tension.

4.12 Comparison of tensile and compressive strength of rebars:

The direct or linear relationship between tensile and compressive strength of rebars was not found but from Table 35, 36 and 37 it was clear that as the diameter of bar increased the compressive strength also increased.

4.13 Comparison of tensile and compressive strength of couplers:

Coupler shows the same behavior as that of rebars i.e. there is no direct or linear relationship between tensile strength and compressive strength but the compressive strength increase as the diameter of coupler increases.

Chapter 5

CONCLUSION AND FUTURE RECOMMENDATION

Conclusion done after analysis and observation of lab results are mentioned below:

5.1 CONCLUSION:

The following salient conclusions are drawn from this study-

a) The coupler gives same or even better strength in comparison to the rebar up to the yield strength and the ultimate strength of coupler is found to be 80% of the strength given by the reinforced bars in tension.

b) The yield strength and ultimate strength of coupler is found to be more than 90% of the strength given by the reinforced bar in compression.

c) The coupler with same or higher grade of steel in comparison with the base metal (reinforcement bar) gives the better performance in both tension and compression.

d) In terms of durability consideration coupler are not more effective as the energy absorbed by them is very lower in comparison with the rebars in tension.

e) In compression, coupler gives better performance in terms of durability.

f) Lager the diameter of the bar longer the lap length required.

g) Small diameter bars can perform well in the short lap length.

h) In term of strength and economic consideration mechanical splicing is found to be superior.

5.2 FURTHER RECOMMENDATION:

1. The composite action between concrete and couple can be studied.
2. The test can be conducted for the performance of the coupler in the reverse cyclic loading.
3. Transition couplers are also in used in the construction, so the behavior assessment of these couplers is also essential.

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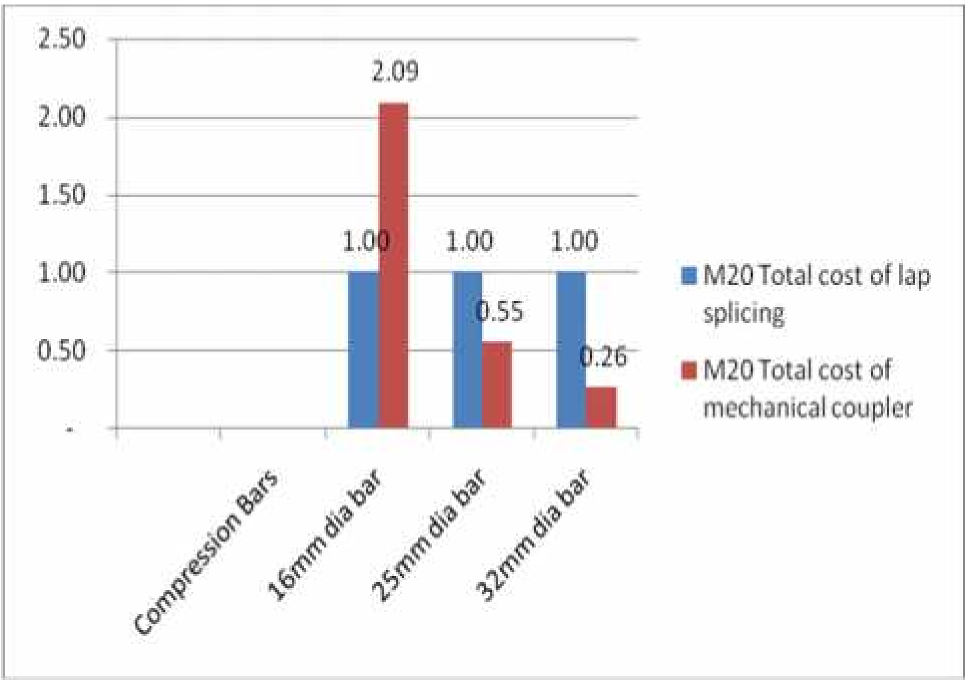
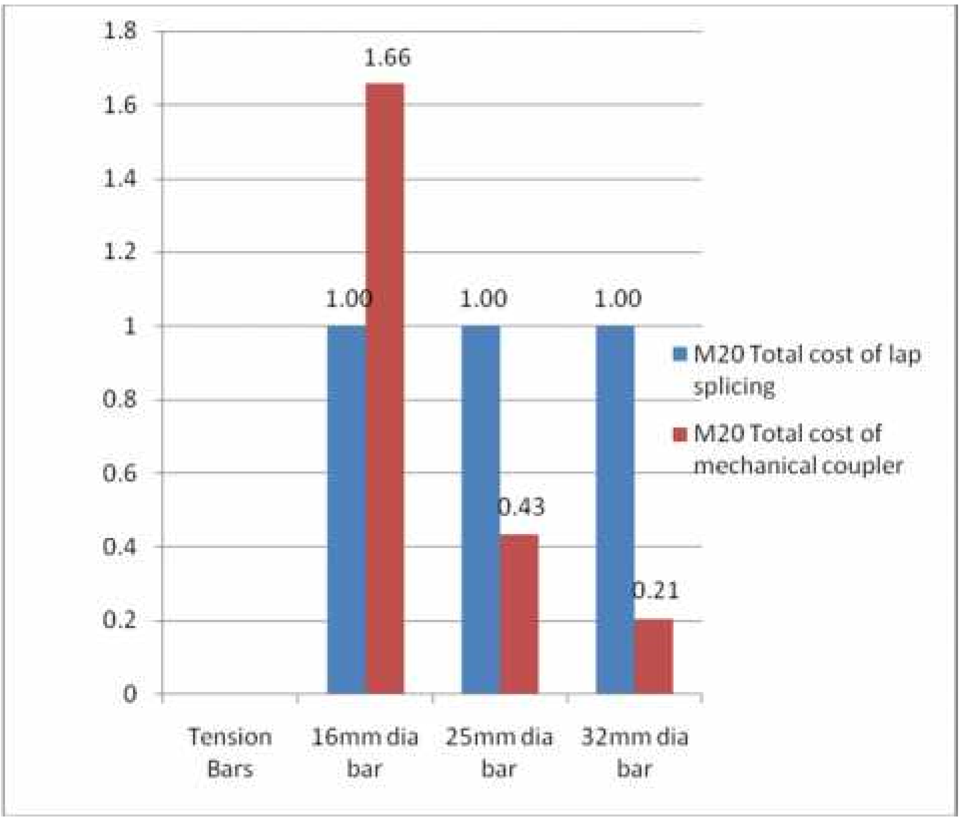
Appendices I

M20

S.N.	Description	Total cost of lap splicing	Total cost of mechanical coupler
	Tension Bars		
	16mm dia bar	1.00	1.66
	25mm dia bar	1.00	0.43
	32mm dia bar	1.00	0.21

M20			
S.N.	**Description**	**Total cost of lap splicing**	**Total cost of mechanical coupler**
	Compression Bars		
	16mm dia bar	1.00	2.09
	25mm dia bar	1.00	0.55
	32mm dia bar	1.00	0.26


2.50
2.00
1.50
1.00
0.50
-
2.09
1.00
1.00
1.00
0.55
0.26
Compression Bars
16mm dia bar
25mm dia bar
32mm dia bar
M20 Total cost of lap splicing
M20 Total cost of mechanical coupler


1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1.66
1.00
1.00
1.00
0.43
0.21
Tension Bars
16mm dia bar
25mm dia bar
32mm dia bar
M20 Total cost of lap splicing
M20 Total cost of mechanical coupler

Appendices II

57.Compression test

57.1 Reinforcement Bar

S.N.	Discription	Length(mm)	Dia(mm) Top	Middle	Bottom	Mean Dia(mm)	Area(mm^2)	Yielding load(N)	Yielding strength(N/mm^2)	Ultimate load(N)	Ultimate strength(N/mm^2)	Remarks
A.	**16ø bar**											
1	SC11	500	16.24	16.12	16.6	16.32	209.27	-	-	48,000.00	229.37	
2	SC12	500	16.2	16.22	16	16.14	204.68	-	-	34,500.00	168.56	
3	SC13	500	16.08	16.18	16.14	16.13	204.51	-	-	30,500.00	149.14	
	Mean							-	**-**		**182.35**	
B.	**25ø bar**											
1	SC21	500	24.70	24.64	24.60	24.65	477.29	-	-	122,500.00	256.66	
2	SC22	500	25.00	24.90	24.80	24.90	487.15	-	-	120,500.00	247.36	
3	SC23	500	24.98	24.82	24.90	24.90	487.15	-	-	206,000.00	422.87	**False sample**
	Mean								**-**		**252.01**	

								-				
C.	**32ø bar**											
1	SC31	500	31.50	31.90	31.82	31.74	791.55	-	-	334,000.00	421.96	**False sample**
2	SC32	500	31.68	31.72	32.00	31.80	794.55	-	-	262,000.00	329.75	
3	SC33	500	31.52	31.42	31.82	31.59	783.92	-	-	275,000.00	350.80	
	Mean							-	**-**		**226.85**	

Appendices III

CHART 1: STRESS-STRAIN DIAGRAM FOR 16MM ø BARS IN TENSION

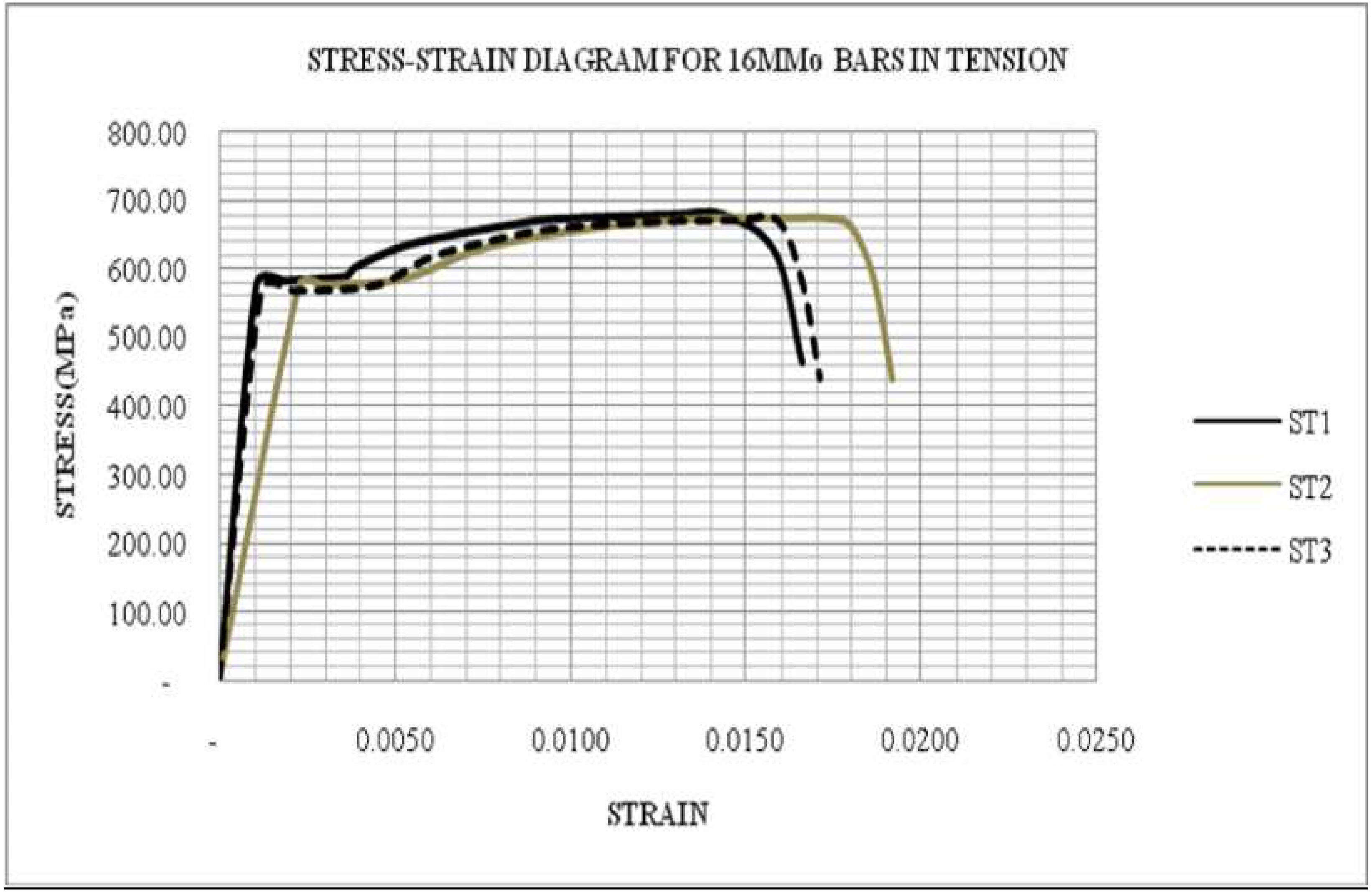


TABLE 1: STRESS-STRAIN VALUES FOR 16MM ø BARS IN TENSION

Table 1.1 Stress-Strain values for ST11

STRESS (MPa)	-	576.05	582.25	588.69	602.09	632.60	651.94	664.84	670.79	675.01	678.73	678.73	623.42	463.44
STRAIN	-	0.0011	0.0019	0.0036	0.0039	0.0052	0.0069	0.0084	0.0092	0.0107	0.0129	0.0144	0.0158	0.0166

Table 1.2 Stress-Strain values for ST12

STRESS (MPa)	-	575.56	577.56	580.56	592.56	622.81	642.81	665.81	675.56	675.06	674.56	660.56	585.56	440.32
STRAIN	-	0.0023	0.0029	0.0045	0.0056	0.0071	0.0085	0.0115	0.0145	0.0159	0.0174	0.0180	0.0187	0.0192

Table 1.3 Stress-Strain values for ST13

STRESS (MPa)	-	567.94	568.51	576.16	614.13	636.80	658.62	669.95	671.65	671.08	580.69	441.28
STRAIN	-	0.0012	0.0021	0.0044	0.0058	0.0073	0.0094	0.0125	0.0147	0.0159	0.0166	0.0171

CHART 2: STRESS-STRAIN DIAGRAM FOR 25MM ø BARS IN TENSION:

TABLE 2: STRESS-STRAIN VALUES FOR 25MM ø BARS IN TENSION

Table 2.1: Stress-Strain values for ST21:

STRESS (MPa)	-	615.76	612.85	614.75	622.47	650.54	677.39	695.28	710.94	733.53	735.55	736.33	720.34	643.61	584.00
STRAIN	-	0.0046	0.0049	0.0056	0.0064	0.0077	0.0092	0.0106	0.0122	0.0143	0.0180	0.0208	0.0220	0.0229	0.0233

Table 2.2: Stress Strain values for ST22:

STRESS (MPa)	-	576.00	579.47	582.83	615.72	639.25	664.51	679.18	687.22	689.87	690.18	686.10	634.36	572.13
STRAIN	-	0.0017	0.0025	0.0036	0.0050	0.0065	0.0087	0.0109	0.0131	0.0146	0.0168	0.0183	0.0194	0.0199

Table 2.3 Stress Strain values for ST23:

STRESS (MPa)	-	568.76	576.03	580.48	584.72	592.30	611.08	635.52	647.14	660.57	672.99	680.26	684.61	638.35	551.90	676.12	638.35	551.90
STRAIN	-	0.0046	0.0055	0.0061	0.0067	0.0071	0.0082	0.0097	0.0106	0.0119	0.0134	0.0149	0.0164	0.0201	0.0209	0.0193	0.0201	0.0209

CHART 3: STRESS-STRAIN DIAGRAM FOR 32MM ø BARS IN TENSION:

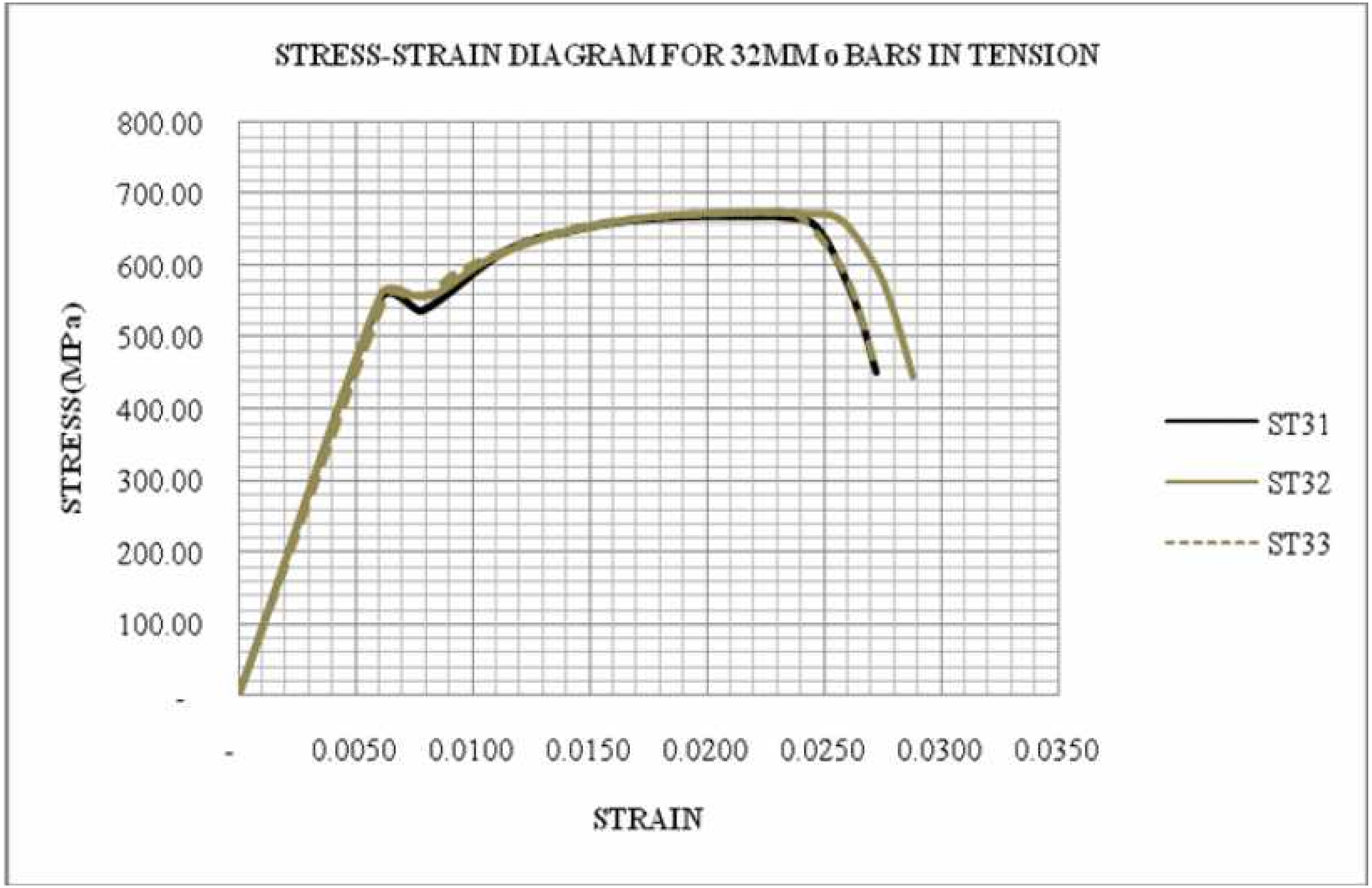


TABLE 3: STRESS-STRAIN VALUES FOR 32MM ø BARS IN TENSION

Table 3.1: Stress-Strain values for ST31:

STRESS (MPa)	-	553.16	537.07	621.71	650.69	662.86	668.35	669.15	669.15	667.95	651.61	551.18	451.93
STRAIN	-	0.0061	0.0078	0.0114	0.0144	0.0166	0.0188	0.0203	0.0218	0.0233	0.0247	0.0263	0.0272

Table 3.2: Stress-Strain values for ST32:

STRESS (MPa)	-	559.34	558.82	561.79	599.66	622.98	647.47	662.08	670.93	673.38	675.13	673.19	664.40	599.01	536.53	446.58
STRAIN	-	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03

Table 3.3: Stress-Strain values for ST33:

STRESS (MPa)	-	556.26	556.65	560.23	585.38	609.69	638.10	656.27	668.56	672.97	673.10	669.01	584.86	455.29
STRAIN	-	0.0063	0.0072	0.0082	0.0091	0.0106	0.0128	0.0150	0.0180	0.0209	0.0224	0.0239	0.0259	0.0272

CHART 4: STRESS-STRAIN DIAGRAM FOR COUPLER USED IN 16MM ø BAR IN TENSION:

TABLE 4: STRESS-STRAIN VALUES FOR COUPLERS USED IN 16MM ø BARS IN TENSION

Table 4.1: Stress-Strain values for CT11:

STRESS (MPa)	-	568.88	581.00	586.57	592.15	601.00	600.23	613.69	621.38	623.30	620.61	571.19	528.31
STRAIN	-	0.0024	0.0026	0.0029	0.0036	0.0044	0.0049	0.0058	0.0066	0.0071	0.0071	0.0073	0.0074

Table 4.2: Stress-Strain values for CT14:

STRESS (MPa)	-	547.88	553.66	555.75	556.15	557.49	541.03	521.94
STRAIN	-	0.0015	0.0019	0.0022	0.0026	0.0041	0.0043	0.0046

Table 4.3: Stress-Strain values for CT15:

STRESS (MPa)	-	567.23	580.62	582.55	585.25	588.70	591.90	575.90	554.78
STRAIN	-	0.0026	0.0032	0.0039	0.0045	0.0055	0.0062	0.0067	0.0070

CHART 5: STRESS-STRAIN DIAGRAM FOR COUPLRS USED IN 25MM ø BARS IN TENSION:

TABLE 5: STRESS-STRAIN VALUES FOR COUPLERS USED IN 25MM ø BARS IN TENSION

Table 5.1: Stress-Strain values for CT21:

STRESS (MPa)	-	339.52	352.96	375.03	405.29	423.61	423.89	404.53	343.47
STRAIN	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5.2: Stress-Strain values for CT22:

STRESS (MPa)	-	342.27	355.86	371.64	392.29	409.68	414.27	414.87	357.46
STRAIN	-	0.0021	0.0025	0.0031	0.0036	0.0043	0.0046	0.0048	0.0050

Table 5.3: Stress-Strain values for CT23:

STRESS (MPa)	-	324.84	333.72	339.74	359.51	381.01	409.66	429.63	429.43	416.06	351.20
STRAIN	-	0.0026	0.0028	0.0030	0.0034	0.0038	0.0044	0.0053	0.0056	0.0058	0.0060

CHART 6: STRESS-STRAIN DIAGRAM FOR COUPLERS USED IN 32MM ø BARS IN TENSION:

TABLE 6: STRESS-STRAIN VALUES FOR COUPLERS USED IN 32MM ø BARS IN TENSION

Table 6.1: Stress-Strain values for CT31:

STRESS (MPa)	-	560.57	561.11	570.74	574.74	574.06	563.28
STRAIN	-	0.0085	0.0092	0.0096	0.0100	0.0101	0.0102

CHART 7: STRESS-STRAIN DIAGRAM FOR 16MM ø BARS IN COMPRESSION:

TABLE 7: STRESS-STRAIN VALUES FOR 16MM ø BARS IN COMPRESSION

Table 7.1: Stress-Strain values for SC11:

STRESS (MPa)	-	117.89	144.83	189.85	211.80	217.88	229.37	228.36	217.88	210.11
STRAIN	-	0.0002	0.0003	0.0004	0.0004	0.0004	0.0005	0.0005	0.0006	0.0006

Table 7.2: Stress-Strain values for SC12:

STRESS (MPa)	-	120.77	129.29	140.03	150.96	154.11	159.67	168.56	155.22	129.29
STRAIN	-	0.0003	0.0004	0.0004	0.0005	0.0005	0.0006	0.0007	0.0007	0.0008

Table 7.3: Stress-Strain values for SC13:

STRESS (MPa)	-	107.17	112.98	133.00	133.97	141.71	149.14	147.85	129.45
STRAIN	-	0.00041	0.00044	0.00054	0.00055	0.00061	0.00068	0.00080	0.00093

CHART 8: STRESS-STRAIN DIAGRAM FOR 25MM ø BARS IN COMPRESSION:

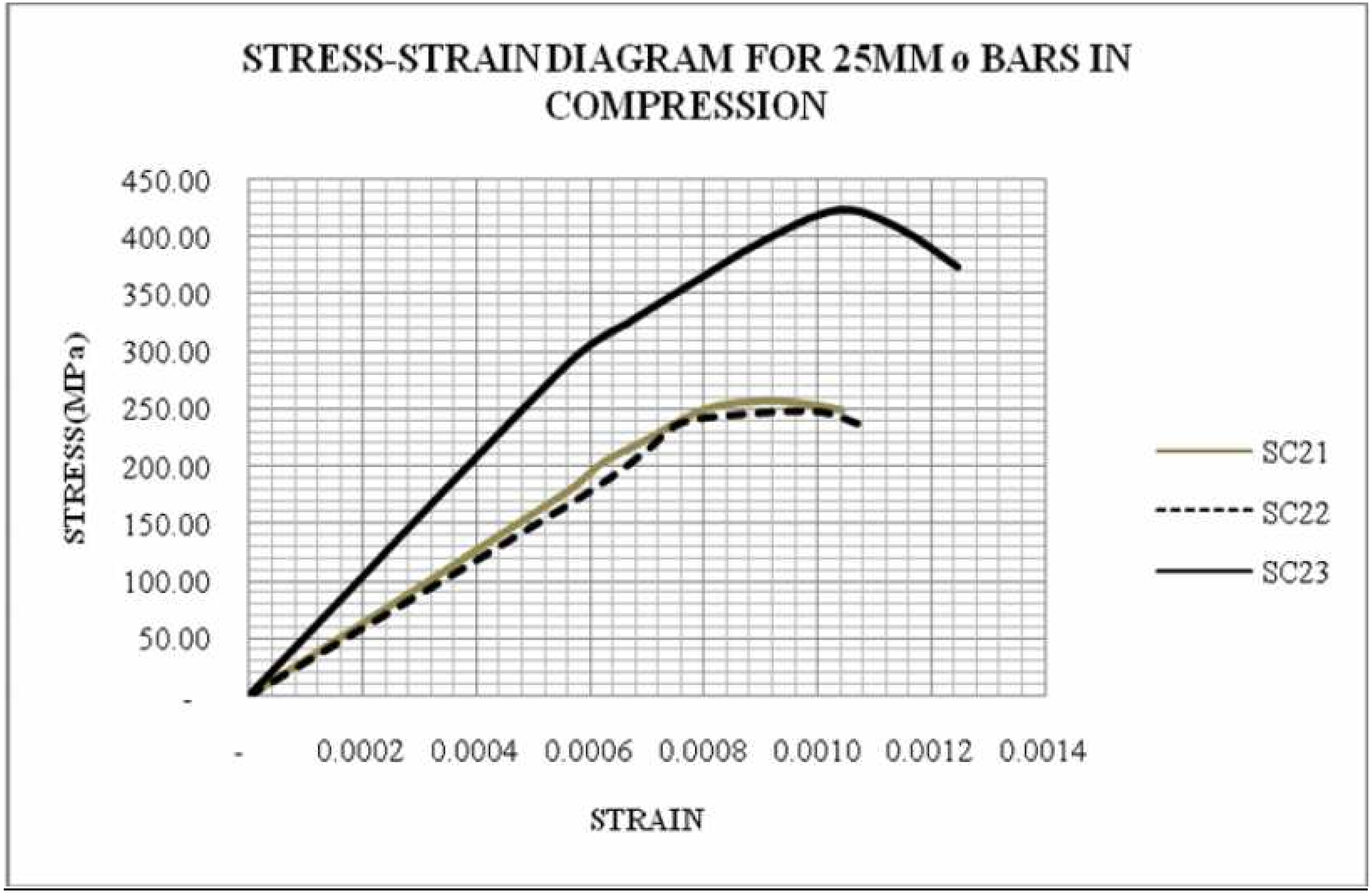


TABLE 8: STRESS-STRAIN VALUES FOR 25MM DIA ø IN COMPRESSION

Table 8.1: Stress-Strain values for SC21:

STRESS (MPa)	-	177.76	188.37	203.72	222.19	249.62	256.66	253.21	248.73
STRAIN	-	0.00056	0.00059	0.00062	0.00070	0.00080	0.00091	0.00099	0.00104

Table 8.2: Stress-Strain values for SC22:

STRESS (MPa)	-	174.10	213.97	217.63	235.09	241.91	247.36	236.00	231.91
STRAIN	-	0.00059	0.00070	0.00071	0.00075	0.00081	0.00099	0.00108	0.00116

Table 8.3: Stress-Strain values for SC23:

STRESS (MPa)	-	289.86	324.92	359.99	362.32	395.05	422.87	407.21	373.19
STRAIN	-	0.00056	0.00067	0.00078	0.00079	0.00090	0.00104	0.00114	0.00125

CHART 9: STRESS-STRAIN DIAGRAM FOR 32MM ø BARS IN COMPRESSION:

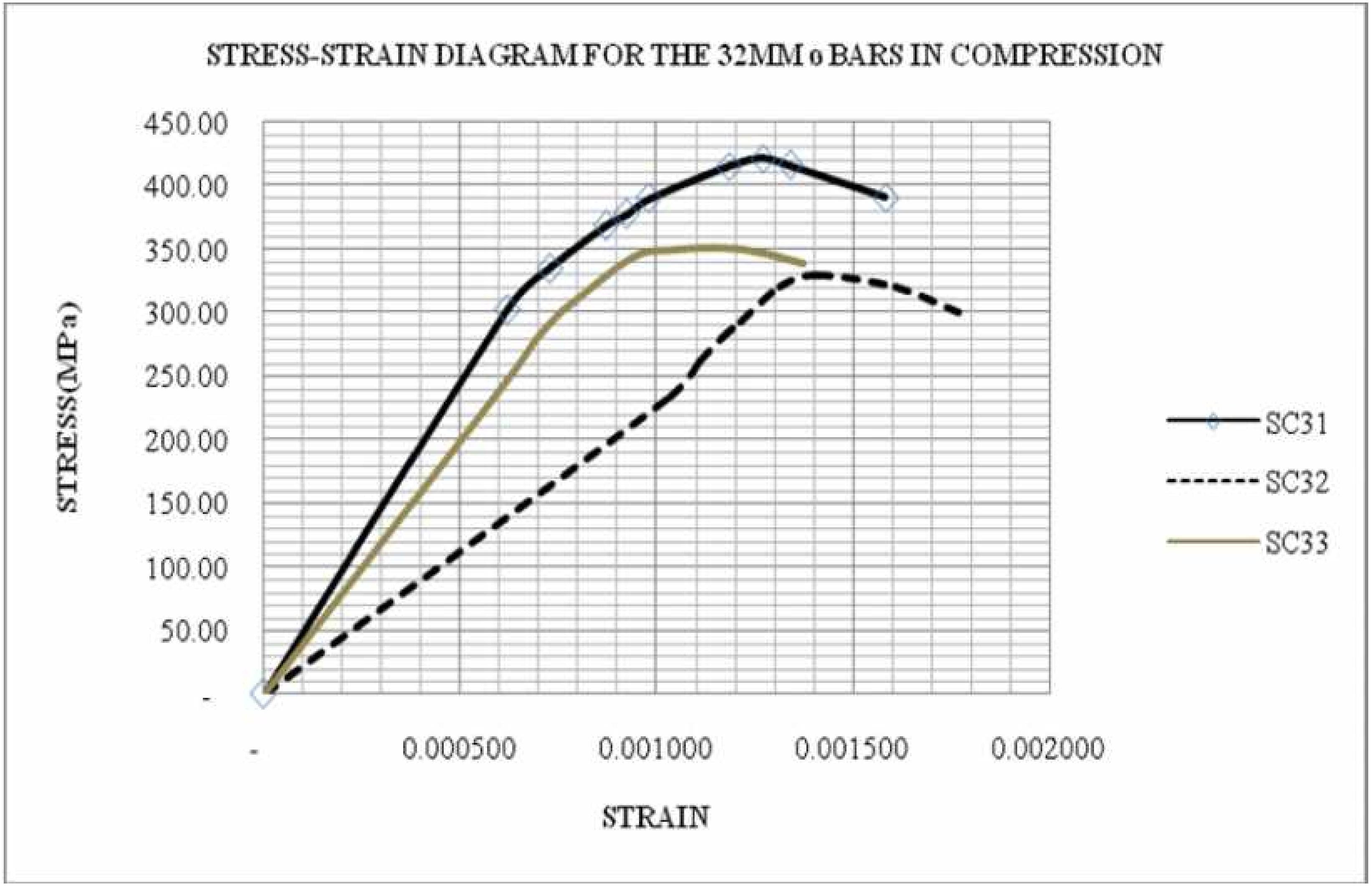


TABLE 9: STRESS-STRAIN VALUES FOR 32MM ø BARS IN COMPRESSION

Table 9.1: Stress-Strain values for SC31:

STRESS (MPa)	-	302.49	334.91	368.40	377.87	389.94	415.49	421.96	416.42	390.74
STRAIN	-	0.00062	0.00073	0.00087	0.00092	0.00098	0.00119	0.00127	0.00134	0.00158

Table 9.2: Stress-Strain values for SC32:

STRESS (MPa)	-	234.36	260.92	280.55	292.95	319.80	329.75	319.80	300.18
STRAIN	-	0.00104	0.00111	0.00117	0.00121	0.00131	0.00141	0.00161	0.00177

Table 9.3: Stress-Strain values for SC33:

STRESS (MPa)	-	246.61	279.13	301.98	308.26	343.49	348.90	350.80	348.67	339.38
STRAIN	-	0.00062	0.00069	0.00076	0.00079	0.00094	0.00105	0.00114	0.00125	0.00137

CHART 10: STRESS-STRAIN DIAGRAM FOR COUPLERS USED IN 16MM ø BARS IN COMPRESSION:

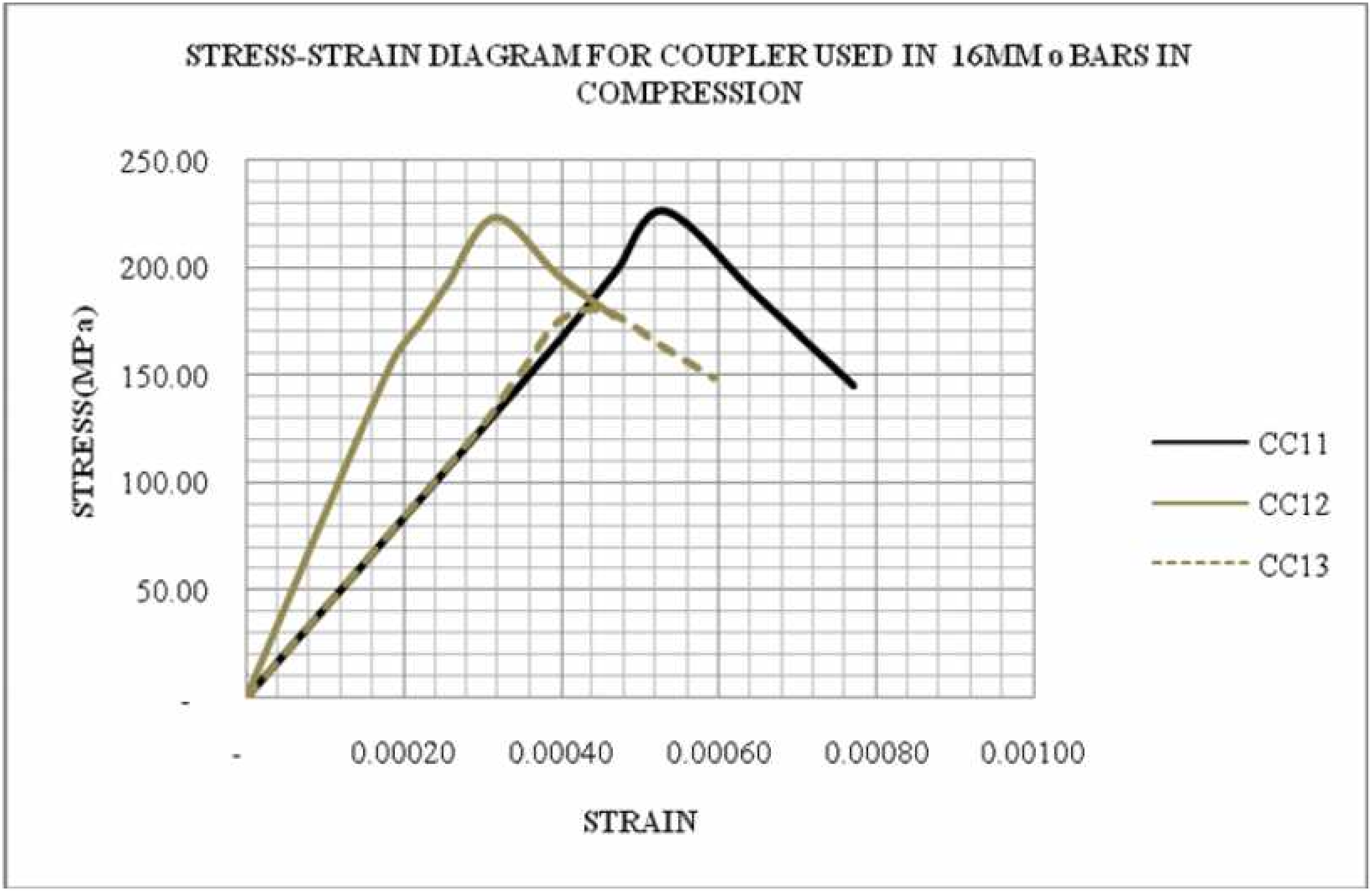


TABLE 10: STRESS-STRAIN VALUES FOR COUPLERS USED IN 16MM ø BARS IN COMPRESSION

Table 10.1: Stress-Strain values for CC11:

STRESS (MPa)	-	160.15	187.17	200.18	227.14	186.89	145.77
STRAIN	-	0.00038	0.00044	0.00047	0.00053	0.00065	0.00077

Table 10.2: Stress-Strain values for CC12:

STRESS (MPa)	-	154.68	173.81	192.25	193.36	224.00	197.37	177.90
STRAIN	-	0.00018	0.00022	0.00025	0.00026	0.00032	0.00039	0.00047

Table 10.3: Stress-Strain values for CC13:

STRESS (MPa)	-	123.77	146.22	154.71	175.97	180.18	163.62	149.03
STRAIN	-	0.00029	0.00034	0.00036	0.00040	0.00046	0.00053	0.00059

CHART 11: STRESS-STRAIN DIAGRAM FOR COUPLER S USED IN 25MM ø BARS IN COMPRESSION:

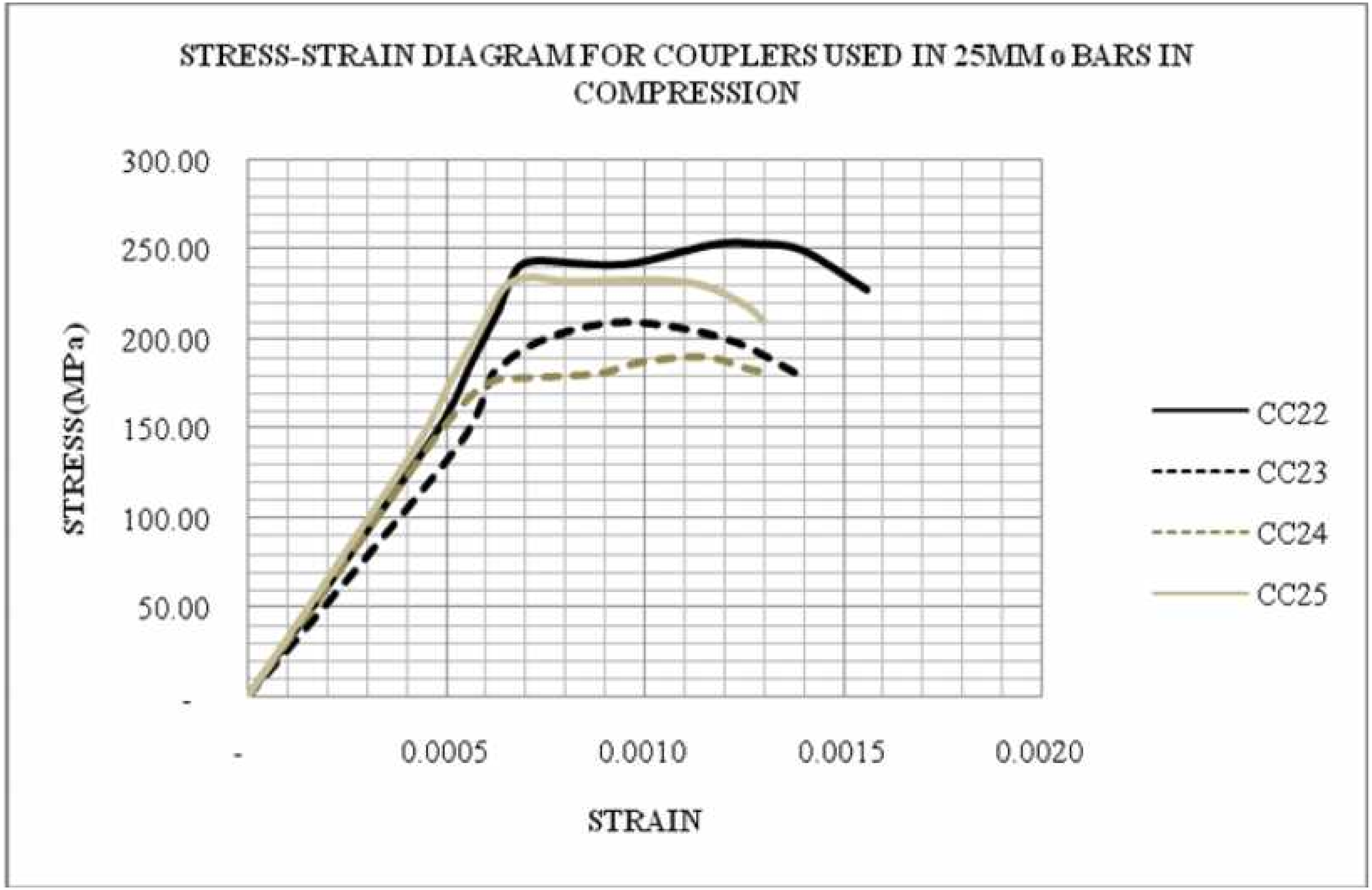

STRESS-STRAIN DIAGRAM FOR COUPLERS USED IN 25MM o BARS IN COMPRESSION
STRESS(MPa)
300.00
250.00
200.00
150.00
100.00
50.00
-
-
0.0005
0.0010
0.0015
0.0020
STRAIN
CC22
CC23
CC24
CC25

TABLE 11: STRESS-STRAIN VALUES FOR COUPLERS USED IN 25MM DIA ø IN COMPRESSION

Table 11.1: Stress-Strain values for CC21:

STRESS (MPa)	-	117.69	138.23	147.12	167.82	161.40	152.11
STRAIN	-	0.00068	0.00076	0.00081	0.00093	0.00115	0.00136

Table 11.2: Stress-Strain values for CC22:

STRESS (MPa)	-	146.99	183.73	192.87	213.75	215.66	238.76	243.65	241.66	252.68	253.29	249.47	227.44
STRAIN	-	0.00047	0.00056	0.00058	0.00063	0.00063	0.00068	0.00073	0.00095	0.00117	0.00128	0.00140	0.00156

Table 11.3: Stress-Strain values for CC23:

STRESS (MPa)	-	141.11	176.39	181.31	198.74	209.41	199.81	178.82
STRAIN	-	0.00053	0.00061	0.00062	0.00073	0.00095	0.00121	0.00140

Table 11.4: Stress-Strain values for CC24:

STRESS (MPa)	-	142.97	168.97	178.17	178.72	181.23	187.73	190.67	183.56	182.58
STRAIN	-	0.00047	0.00056	0.00063	0.00068	0.00088	0.00099	0.00115	0.00127	0.00131

Table 11.5: Stress-Strain values for CC25:

STRESS	-	139.99	173.67	174.99	192.06	210.16	229.66	234.91	232.69	232.34	219.97	210.16

(MPa)												
STRAIN	-	0.00042	0.00050	0.00051	0.00055	0.00060	0.00065	0.00072	0.00081	0.00110	0.00125	0.00130

CHART 12: STRESS-STRAIN DIAGRAM FOR COUPLERS USED IN 32MM ø BARS IN COMPRESSION:

TABLE 12: STRESS-STRAIN VALUES FOR COUPLERS USED IN 32MM ø BARS IN COMPRESSION

Table 12.1: Stress-Strain values for CC31:

STRESS (MPa)	-	228.08	246.52	267.64	285.09	288.76	309.87	319.59	319.17	309.87	302.06
STRAIN	-	0.00	0.00104	0.00123	0.00138	0.00141	0.00161	0.00184	0.00197	0.00215	0.00228

Table 12.2: Stress-Strain values for CC32:

STRESS (MPa)	-	227.44	247.05	257.42	263.42	269.55	284.30	287.40	287.81	282.69	279.59	269.55
STRAIN	-	0.00080	0.00085	0.00102	0.00114	0.00121	0.00141	0.00145	0.00151	0.00156	0.00163	0.00171

CHART 13: NORMALIZED STRESS-STRAIN DIAGRAM FOR 16MM ø BARS IN TENSION:

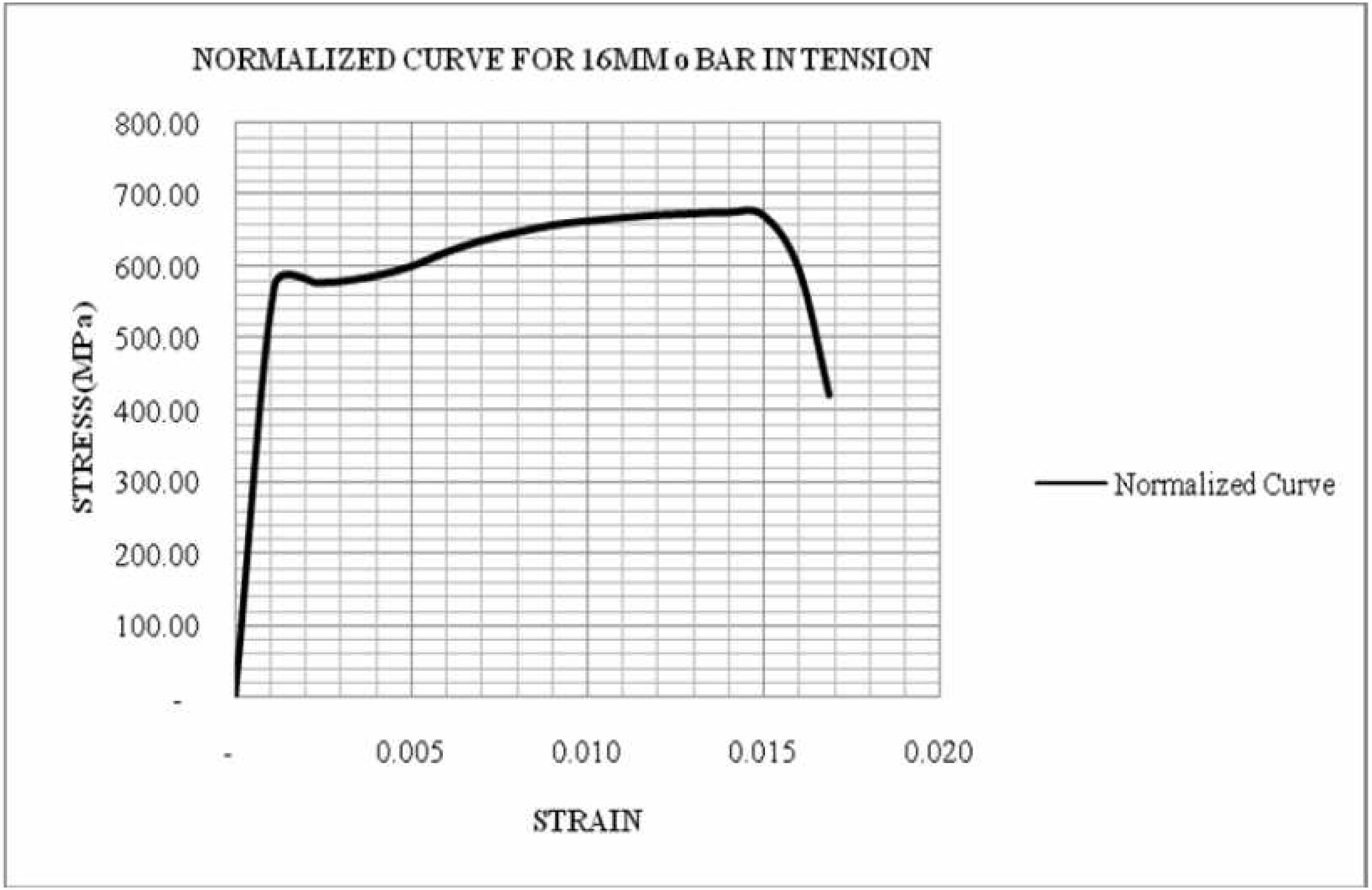


CHART 14: NORMALIZED STRESS-STRAIN DIAGRAM FOR 25MM ø BARS IN TENSION:

CHART 15: NORMALIZED STRESS-STRAIN DIAGRAM FOR 32MM ø BARS IN TENSION:

TABLE 13: NORMALIZED STRESS-STRAIN VALUES FOR 16MM ø BARS IN TENSION

STRESS	-	573.18	576.24	578.51	586.34	599.40	619.18	635.23	646.80	656.67	662.67	667.30

(MPa)											
STRAIN	-	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.010	0.011

STRESS (MPa)	671.12	673.03	674.76	670.40	595.90	421.13
STRAIN	0.012	0.013	0.014	0.015	0.016	0.017

TABLE 14: NORMALIZED STRESS-STRAIN VALUES FOR 25MM ø BARS IN TENSION

STRESS (MPa)	-	586.84	587.50	591.35	600.89	625.13	641.93	656.72	664.30	673.96	682.75	689.44
STRAIN	-	0.0036	0.0040	0.0047	0.0057	0.0070	0.0080	0.0090	0.0097	0.0107	0.0117	0.0127

STRESS (MPa)	695.68	700.83	702.96	703.30	701.50	687.93	675.83	654.12
STRAIN	0.0137	0.0147	0.0157	0.0167	0.0177	0.0187	0.0194	0.0200

TABLE 15: NORMALIZED STRESS-STRAIN VALUES FOR 32MM ø BARS IN TENSION

STRESS (MPa)	-	553.34	553.83	573.96	595.04	613.34	627.48	638.17	647.69	655.08	660.05	664.49
STRAIN	-	0.0070	0.0080	0.0090	0.0100	0.0110	0.0120	0.0130	0.0140	0.0150	0.0160	0.0170

STRESS (MPa)	668.21	670.21	671.37	672.16	672.39	671.55	679.08	641.38	597.49	517.27	478.69
STRAIN	0.0180	0.0190	0.0200	0.0210	0.0220	0.0230	0.0240	0.0250	0.0260	0.0270	0.0275

CHART 16: NORMALIZED STRESS-STRAIN DIAGRAM FOR COUPLERS USED IN 16MM ø BARS IN TENSION:

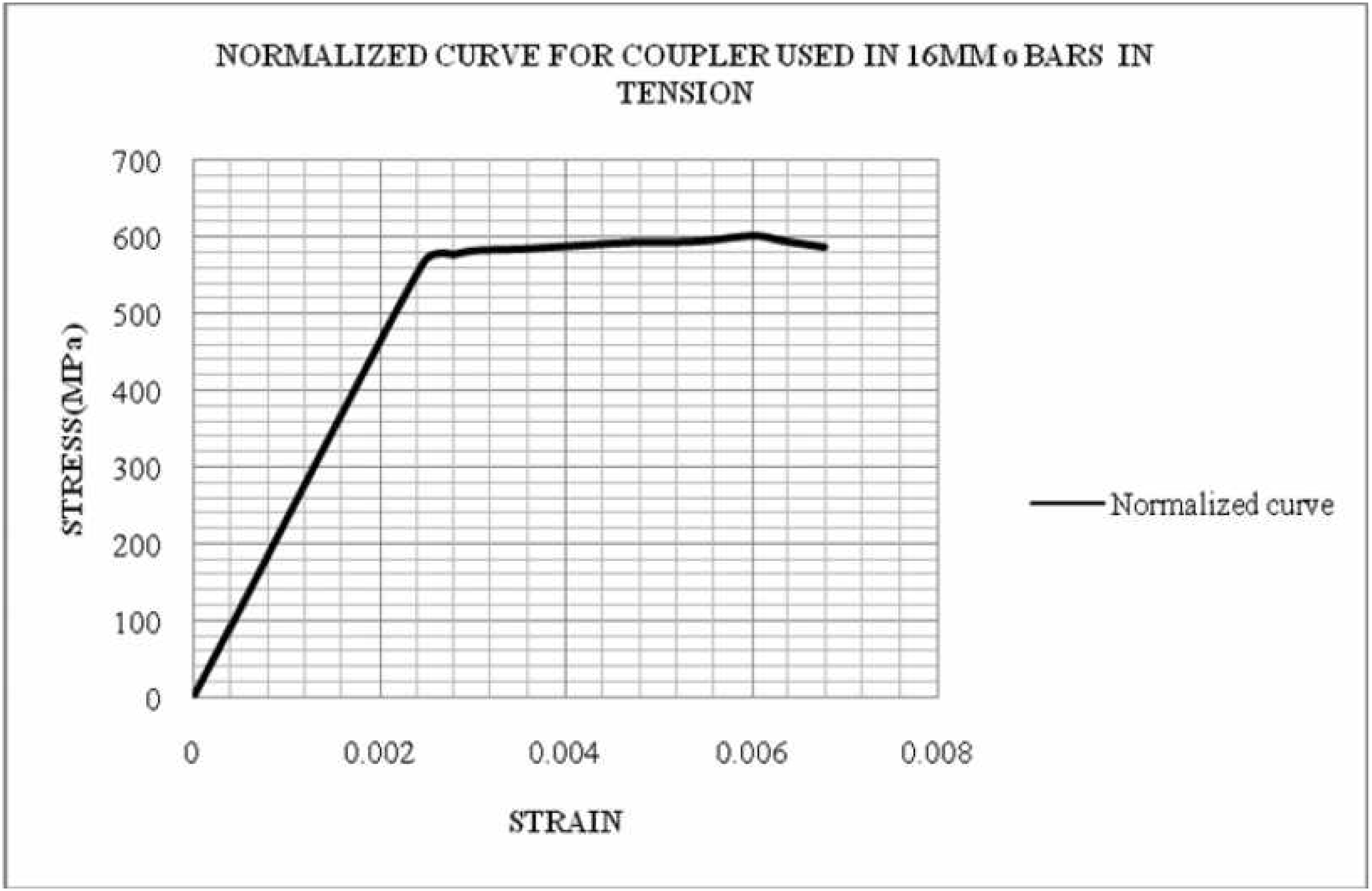


CHART 17: NORMALIZED STRESS-STRAIN DIAGRAM FOR COUPLERS USED IN 25MM ø BARS IN TENSION:

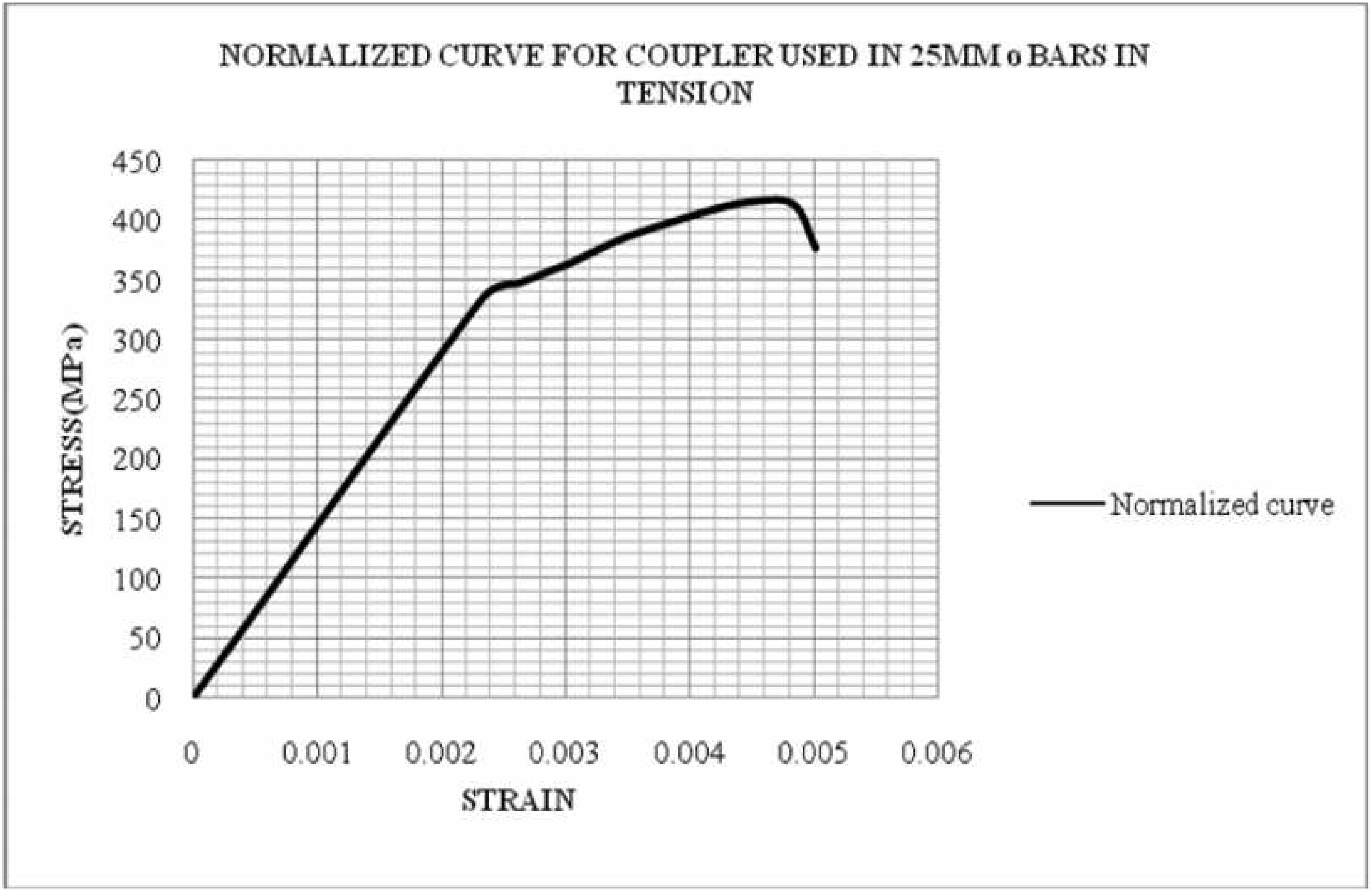


CHART 18: NORMALIZED STRESS-STRAIN DIAGRAM FOR COUPLERS USED IN 32MM ø BARS IN TENSION

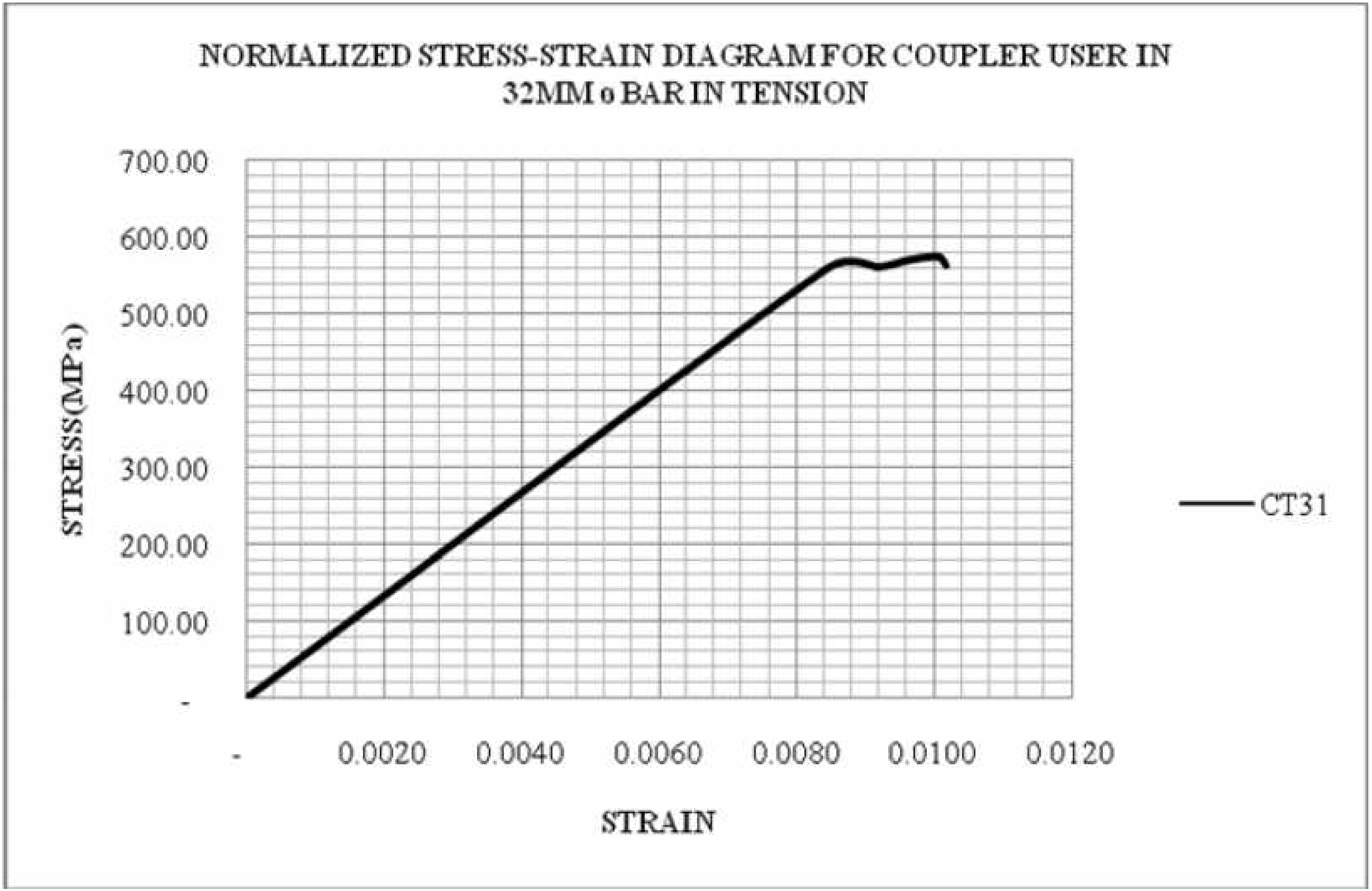


TABLE 16: NORMALIZED STRESS-STRAIN VALUES FOR COUPLERS USED IN 16MM ø BARS IN TENSION

STRESS (MPa)	-	568.06	578.45	583.60	585.12	587.52	590.97	593.99	594.46	596.44	602.79	595.77	588.08

STRAIN	-	0.0025	0.0028	0.0030	0.0035	0.0038	0.0043	0.0047	0.0052	0.0055	0.0060	0.0063	0.0068

TABLE 17: NORMALIZED STRESS-STRAIN VALUES FOR COUPLERS USED IN 25MM ø BARS IN TENSION

STRESS (MPa)	-	335.543	347.512	360.814	364.871	385.697	401.315	407.906	415.940	414.059	377.082
STRAIN	-	0.0023	0.0026	0.0029	0.0030	0.0035	0.0039	0.0041	0.0045	0.0048	0.0050

TABLE 18: NORMALIZED STRESS-STRAIN VALUES FOR COUPLERS USED IN 32MM ø BARS IN TENSION

STRESS (MPa)	-	560.57	561.11	570.74	574.74	574.06	563.28
STRAIN	-	0.0085	0.0092	0.0096	0.0100	0.0101	0.0102

CHART 19: NORMALIZE STRESS-STRAIN DIAGRAM FOR 16MM ø BARS IN COMPRESSION:

CHART 20: NORMALIZE STRESS-STRAIN DIAGRAM FOR 25MM ø BARS IN COMPRESSION:

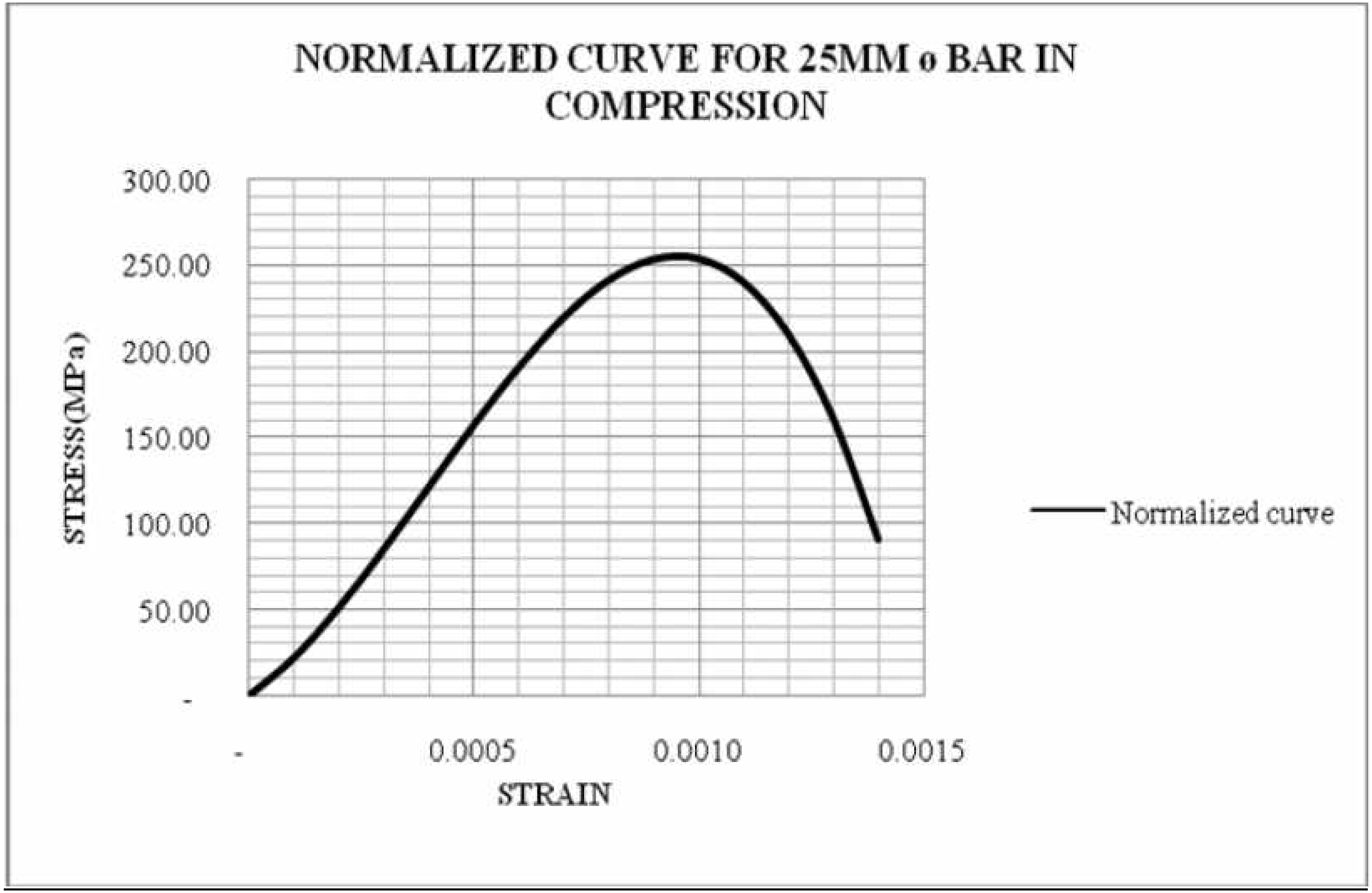


CHART 21: NORMALIZE STRESS-STRAIN DIAGRAM FOR 32MM ø BARS IN COMPRESSION:

TABLE 19: NORMALIZED STRESS-STRAIN VALUES FOR 16MM ø BARS IN COMPRESSION

STRESS	-	55.13	99.98	134.54	158.83	172.82	176.53	169.96	153.11	125.97	88.55	40.84

(MPa)												
STRAIN	-	0.0001	0.0002	0.0003	0.0004	0.0005	0.0006	0.0007	0.0008	0.0009	0.0010	0.0011

TABLE 20: NORMALIZED STRESS-STRAIN VALUES FOR 25MM ø BARS IN COMPRESSION

STRESS (MPa)	-	21.95	50.93	84.57	120.54	156.48	190.03	218.87	240.62	252.95	253.50	239.92
STRAIN	-	0.0001	0.0002	0.0003	0.0004	0.0005	0.0006	0.0007	0.0008	0.0009	0.0010	0.0011

STRESS (MPa)	209.87	161.00	90.94
STRAIN	0.0012	0.0013	0.0014

TABLE 21: NORMALIZED STRESS-STRAIN VALUES FOR 32MM ø BARS IN COMPRESSION

STRESS (MPa)	-	48.84	93.89	135.15	172.62	206.30	236.19	262.30	284.61	303.13	317.86	328.80
STRAIN	-	0.0001	0.0002	0.0003	0.0004	0.0005	0.0006	0.0007	0.0008	0.0009	0.0010	0.0011

STRESS (MPa)	335.95	339.31	338.88	334.66	326.65	314.85	299.27	279.89	256.72	229.76	199.01	164.47
STRAIN	0.0012	0.0013	0.0014	0.0015	0.0016	0.0017	0.0018	0.0019	0.0020	0.0021	0.0022	0.0023

STRESS (MPa)	126.14	84.02
STRAIN	0.0024	0.0025

CHART 22: NORMALIZE STRESS-STRAIN DIAGRAM FOR COUPLERS USED IN 16MM ø BARS IN COMPRESSION:

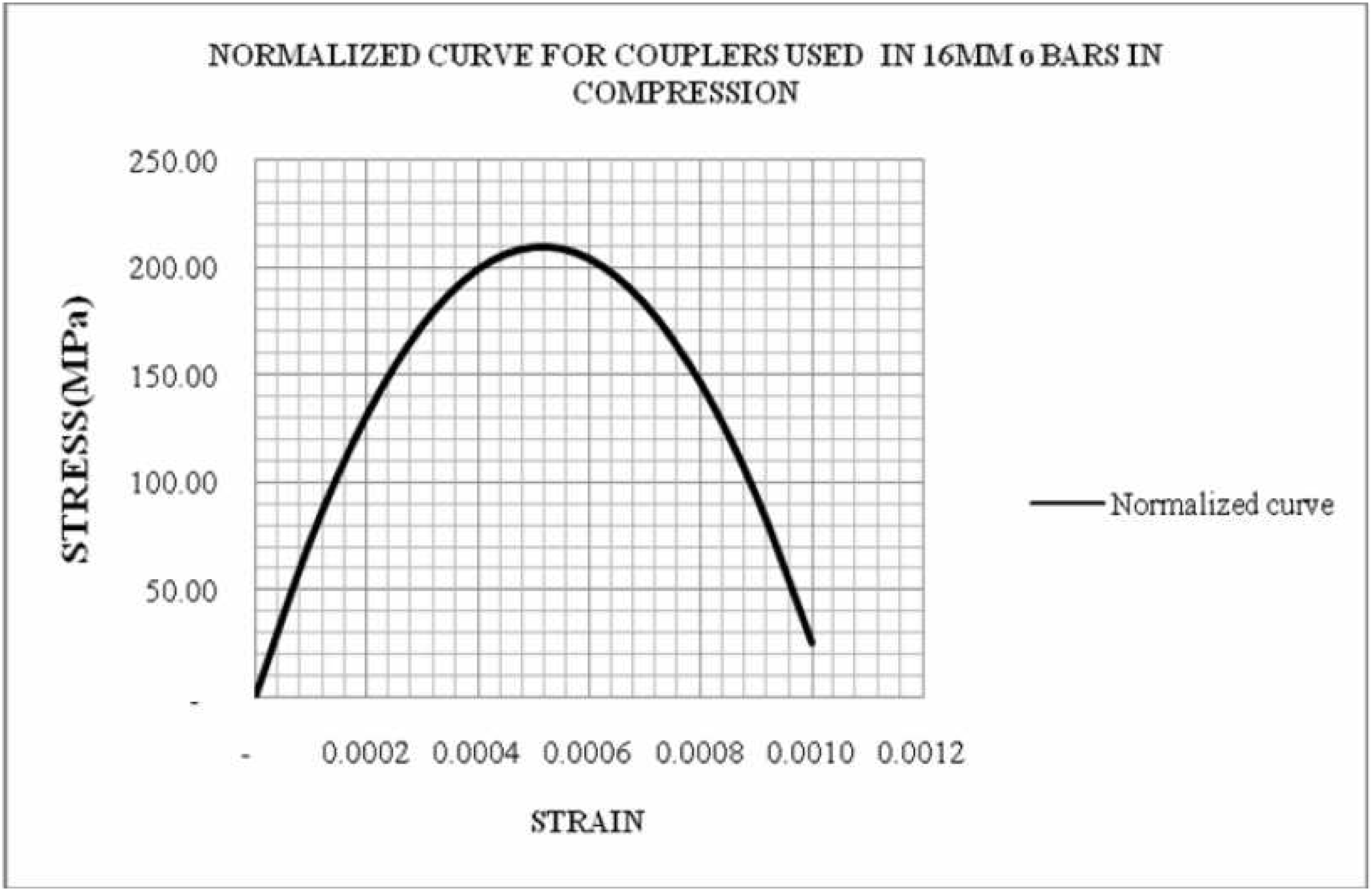


CHART 23: NORMALIZE STRESS-STRAIN DIAGRAM FOR COUPLERS USED IN 25MM ø BARS IN COMPRESSION:

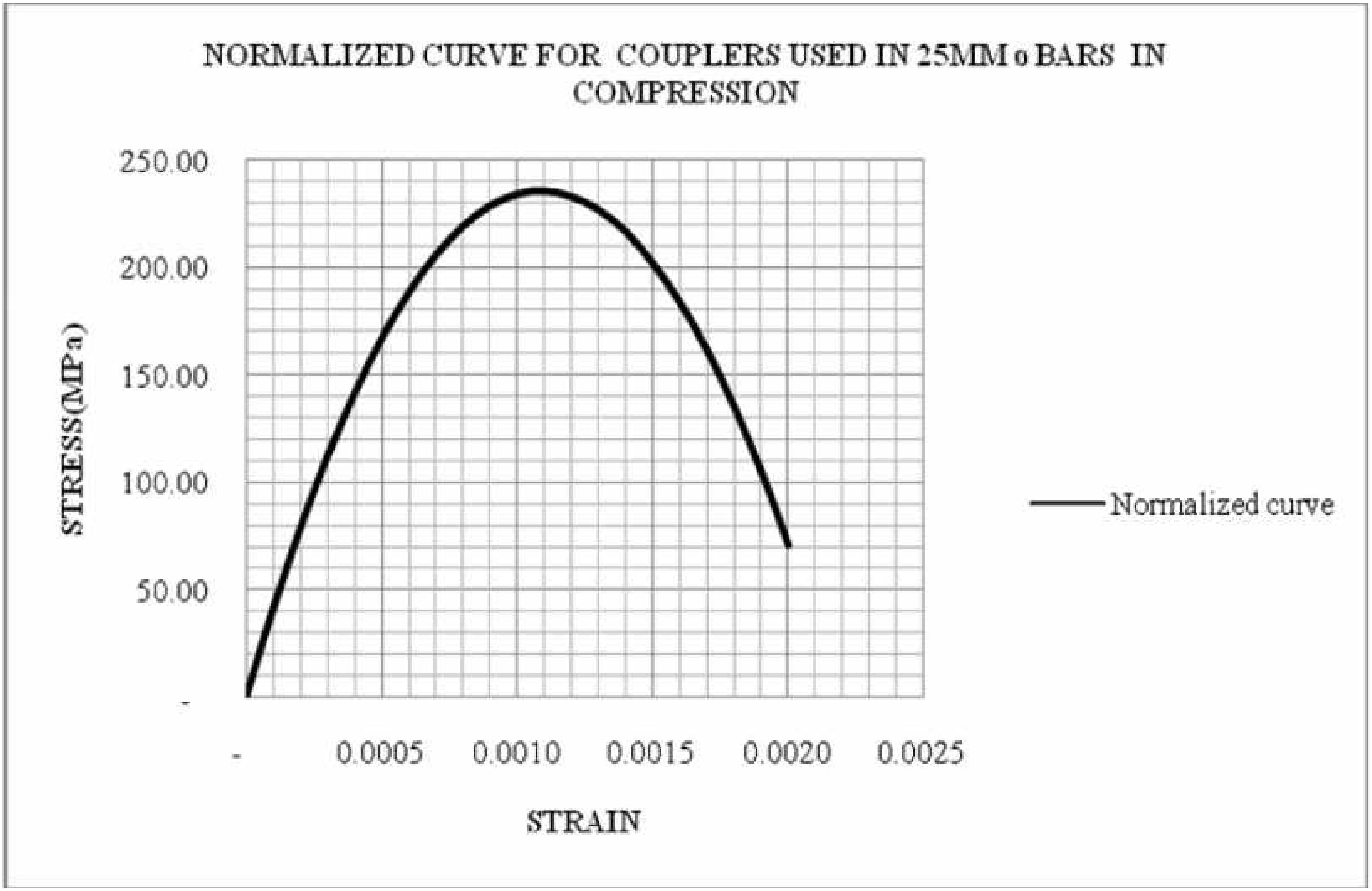
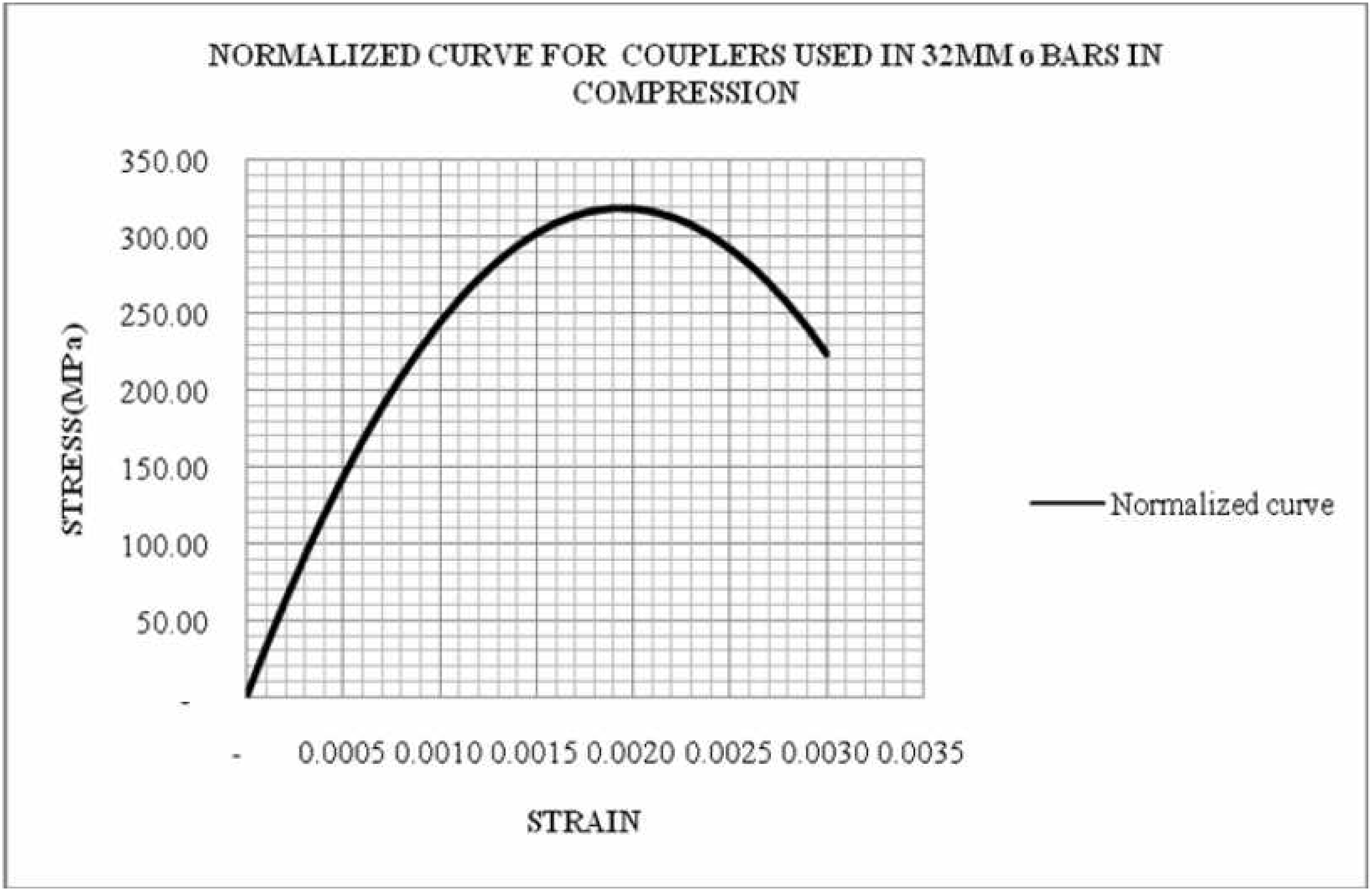


CHART 24: NORMALIZE STRESS-STRAIN DIAGRAM FOR COUPLERS USED IN 32MM ø BARS IN COMPRESSION:



<u>TABLE 22: NORMALIZED STRESS-STRAIN VALUES FOR COUPLERS USED IN 16MM ø BARS IN COMPRESSION</u>

STRESS (MPa)	-	73.44	131.13	173.08	199.28	209.74	204.45	183.42	146.64	94.12	25.86
STRAIN	-	0.0001	0.0002	0.0003	0.0004	0.0005	0.0006	0.0007	0.0008	0.0009	0.0010

TABLE 23: NORMALIZED STRESS-STRAIN VALUES FOR COUPLERS USED IN 25MM ø BARS IN COMPRESSION

STRESS (MPa)	-	41.29	78.60	111.94	141.31	166.71	188.14	205.60	219.08	228.59	234.14	235.70
STRAIN	-	0.0001	0.0002	0.0003	0.0004	0.0005	0.0006	0.0007	0.0008	0.0009	0.0010	0.0011

STRESS (MPa)	233.02	226.93	216.82	202.26	183.97	161.71	135.48	105.28	71.10
STRAIN	0.0012	0.0013	0.0014	0.0015	0.0016	0.0017	0.0018	0.0019	0.0020

TABLE 24: NORMALIZED STRESS-STRAIN VALUES FOR COUPLERS USED IN 32MM ø BARS IN COMPRESSION

STRESS (MPa)	-	32.03	62.37	91.02	117.98	143.24	166.81	188.69	208.87	227.36	244.16	259.26
STRAIN	-	0.0001	0.0002	0.0003	0.0004	0.0005	0.0006	0.0007	0.0008	0.0009	0.0010	0.0011

STRESS (MPa)	272.68	284.40	294.42	302.76	309.40	314.35	317.60	319.16	319.03	317.21	313.69	308.48
STRAIN	0.0012	0.0013	0.0014	0.0015	0.0016	0.0017	0.0018	0.0019	0.0020	0.0021	0.0022	0.0023

STRESS (MPa)	301.58	292.99	282.70	270.72	257.04	241.68	224.62
STRAIN	0.0024	0.0025	0.0026	0.0027	0.0028	0.0029	0.0030

CHART 25: COMPARISION OF STRESS-STRAIN DIAGRAM FOR 16MM ø BARS AND COUPLERS IN TENSION:

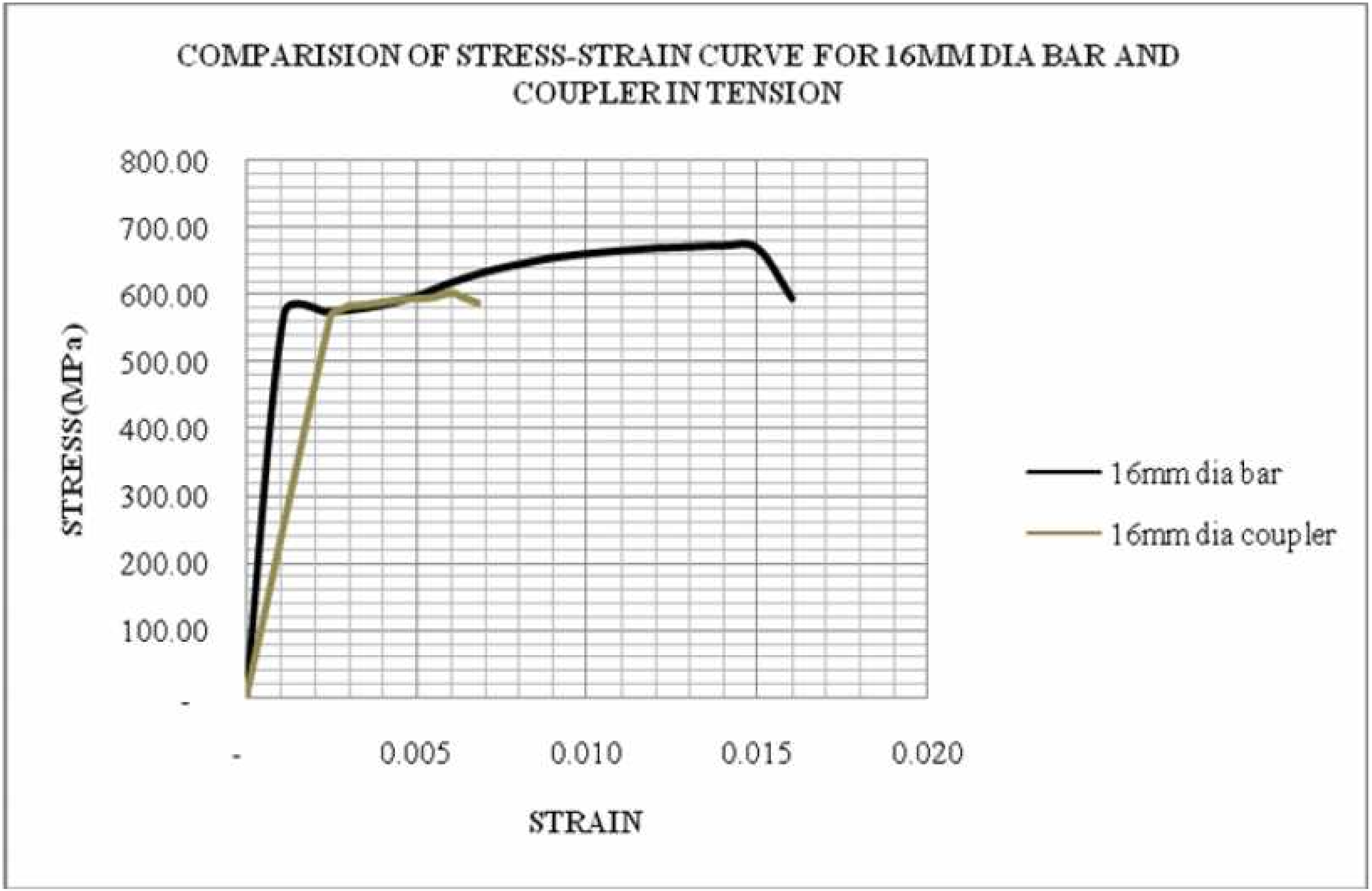


CHART 26: COMPARISION OF STRESS-STRAIN DIAGRAM FOR 25MM ø BARS AND COUPLERS IN TENSION:

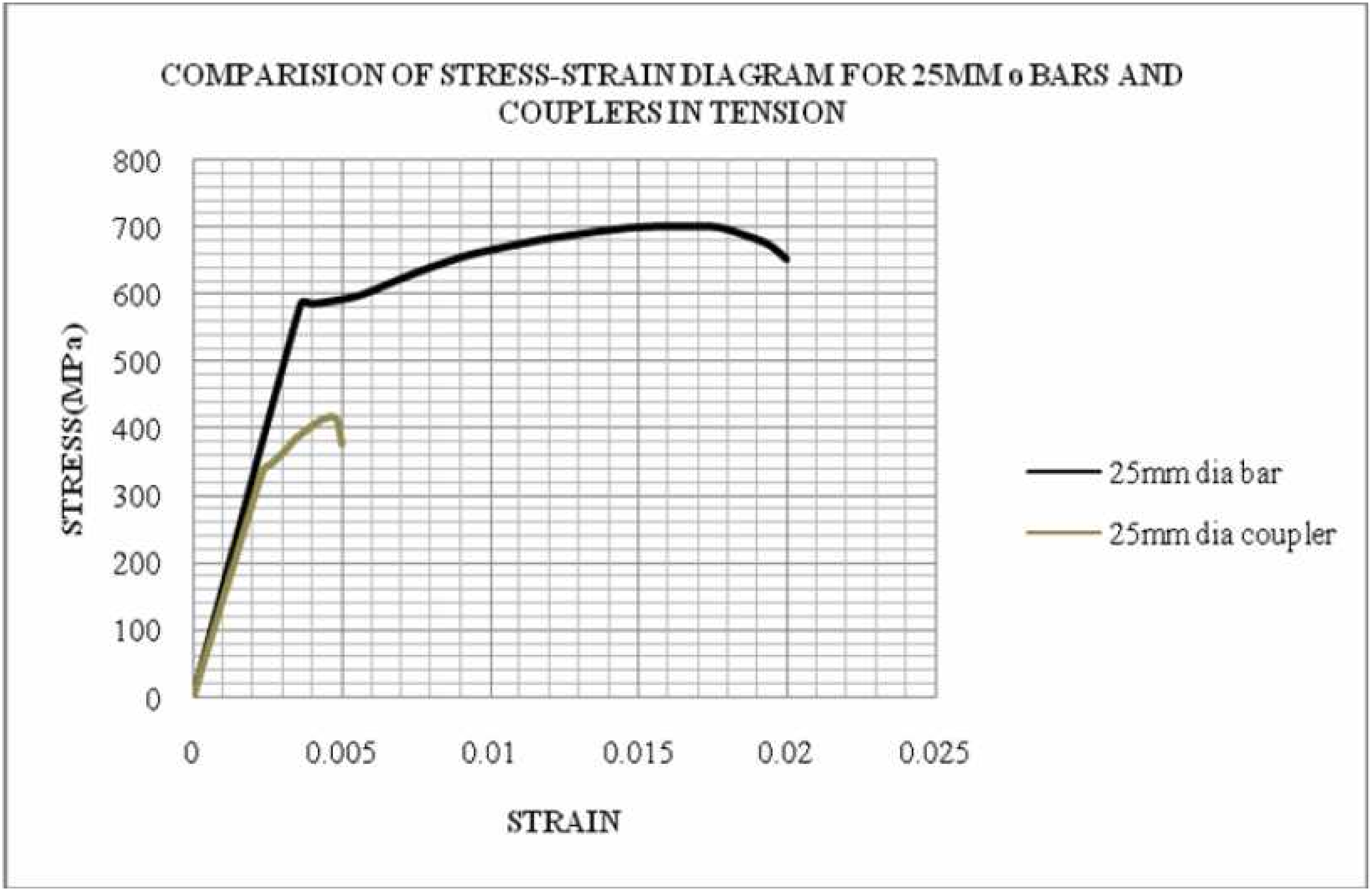


CHART 27: COMPARISION OF STRESS-STRAIN DIAGRAM FOR 32MM ø BARS AND COUPLERS IN TENSION:

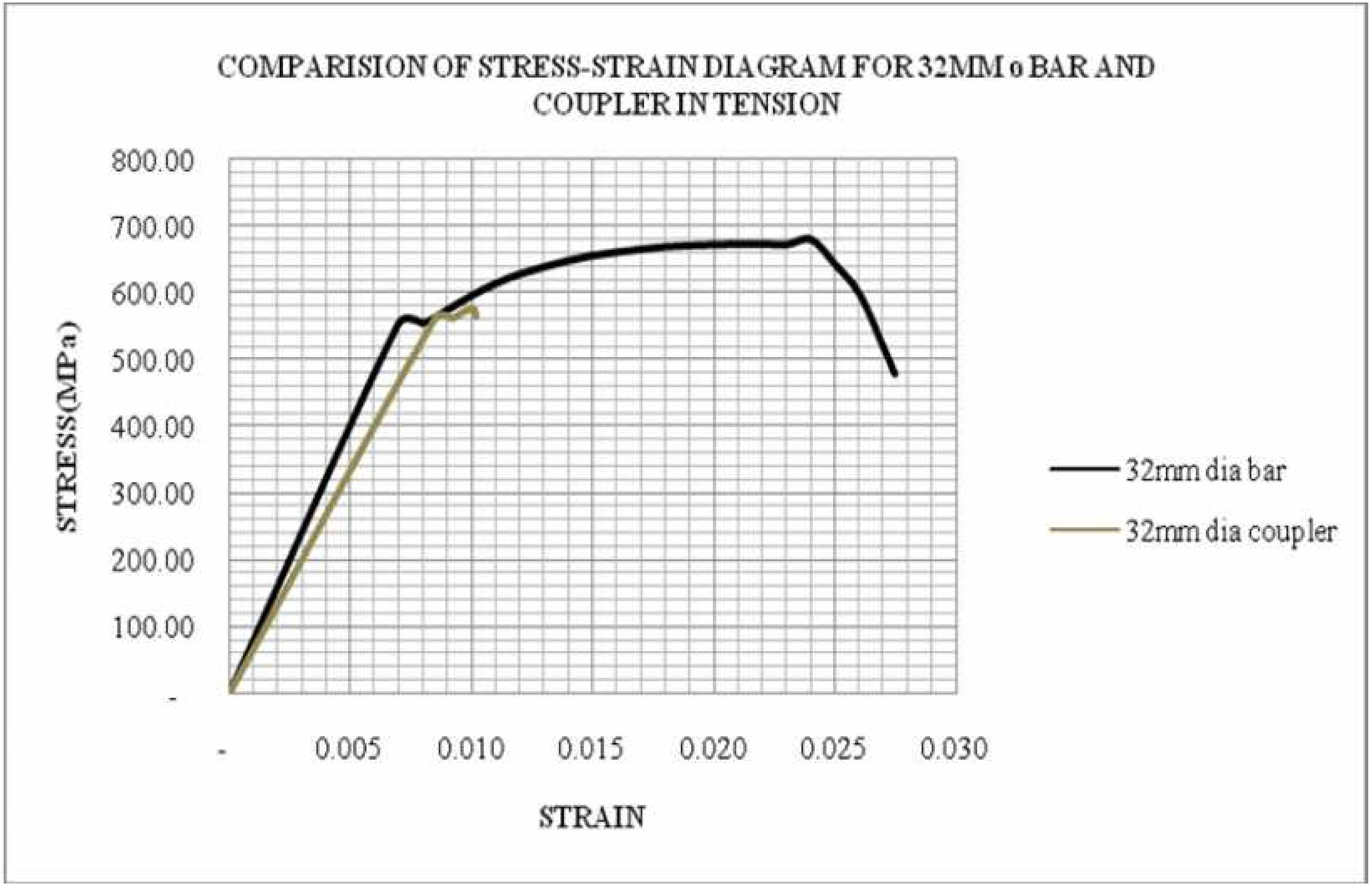


TABLE 25: COMPARISON OF 16MM ø BARS AND COUPLERS IN TENSION

S.N.	Yield strength	Ultimate strength	Ratio (Ultimate/yield)	Remarks

	(Mpa)	(Mpa)		
16mm ø bar	573.18	674.76	1.18	
Coupler	568.06	602.79	1.06	
% strength achieved by the coupler	99.11	89.33		

TABLE 26: COMPARISON OF 25MM ø BARS AND COUPLERS IN TENSION

S.N.	Yield strength (Mpa)	Ultimate strength (Mpa)	Ratio (Ultimate/yield)	Remarks
25mm ø bar	586.84	703.30	1.20	
Coupler	335.54	415.94	1.24	
% strength achieve by the coupler	57.18	59.14		

TABLE 27: COMPARISON OF 32MM ø BARS AND COUPLERS IN TENSION

S.N.	Yield strength (Mpa)	Ultimate strength (Mpa)	Ratio (Ultimate/yield)	Remarks
32mm ø bar	553.34	679.08	1.23	
Coupler	560.57	574.74	1.03	
% strength achieve by the coupler	101.31	84.69		

CHART 28: COMPARISION OF STRESS-STRAIN DIAGRAM FOR VARIOUS ø BAR AND COUPLER IN TENSION:

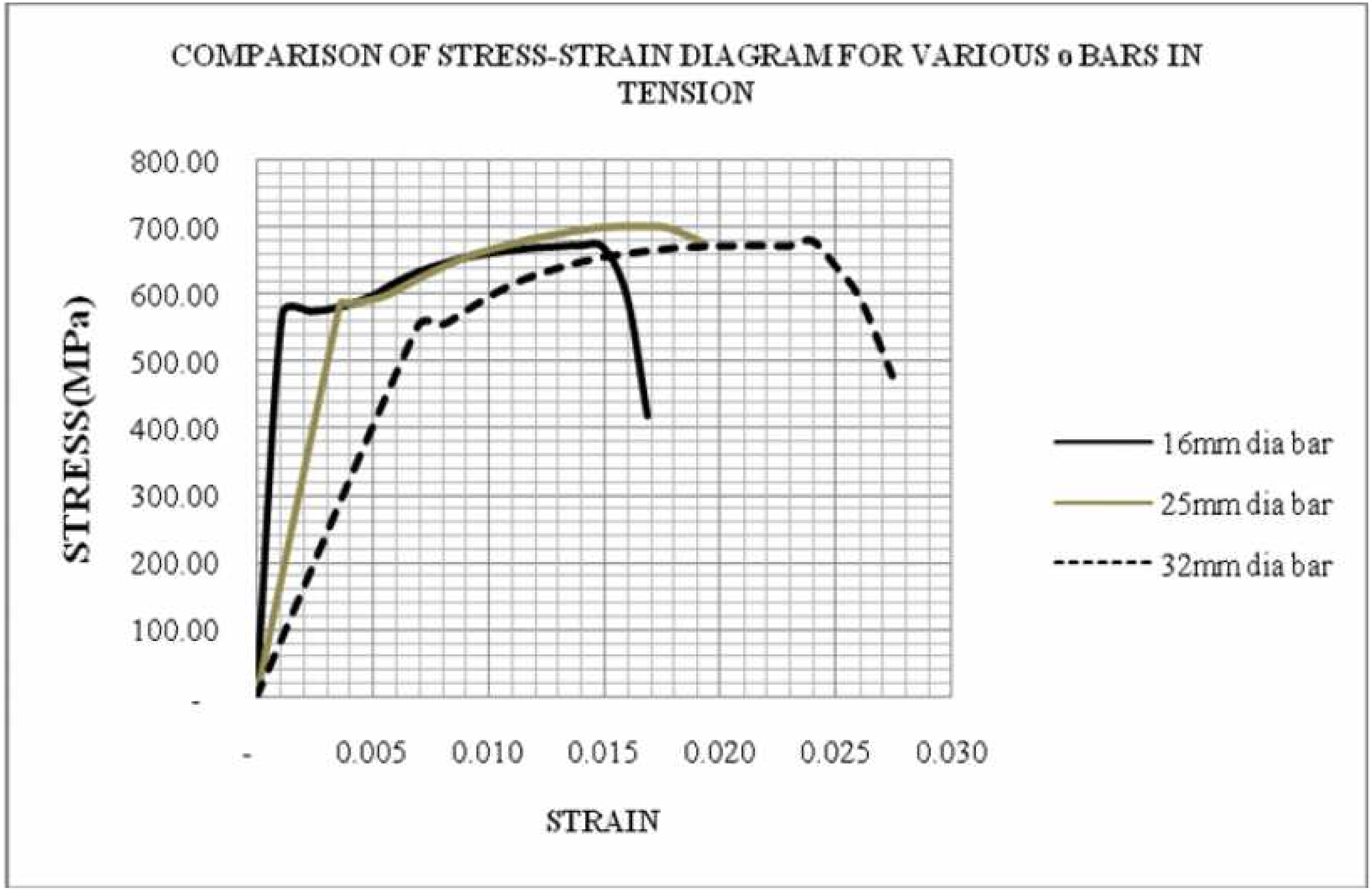


CHART 29: COMPARISION OF STRESS-STRAIN DIAGRAM FOR VARIOUS COUPLERS IN TENSION:

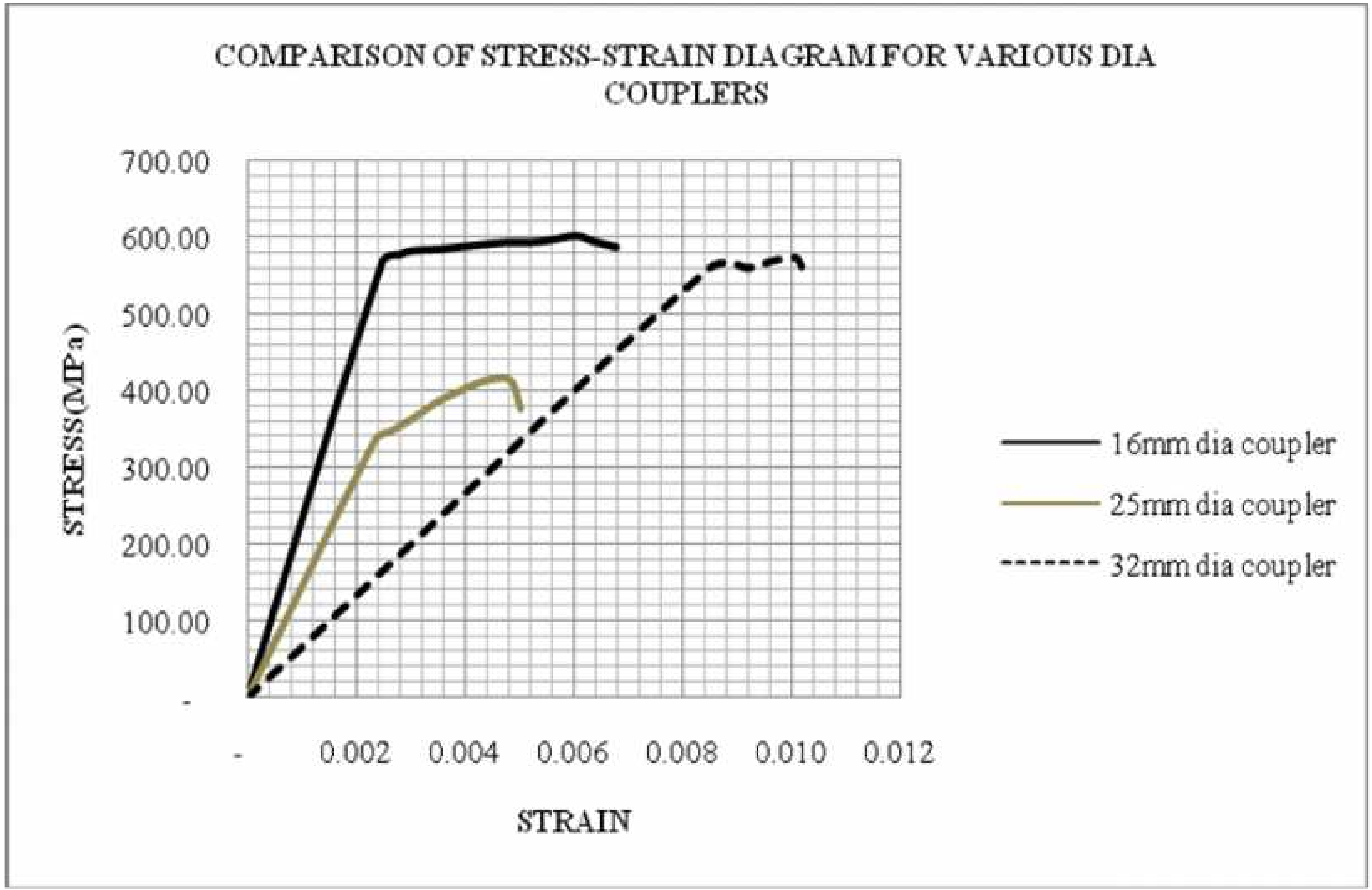


TABLE 28: COMPARISON OF VARIOUS ø BARS IN TENSION

S.N.	Yield strength (Mpa)	Ultimate strength (Mpa)	Ratio (Ultimate/yield)	Remarks
16mm ø bar	573.18	674.76	1.18	
25mm ø bar	586.84	703.30	1.20	
32mm ø bar	553.34	679.08	1.23	

TABLE 29: COMPARISON OF VARIOUS ø COUPLERS IN TENSION

S.N.	Yield strength (Mpa)	Ultimate strength (Mpa)	Ratio (Ultimate/yield)	Remarks
COUPLER USED IN 16MM ø BAR	568.06	602.79	1.06	
COUPLER USED IN 25MM ø BAR	335.54	415.94	1.24	
COUPLER USED IN 32MM ø BAR	560.57	574.74	1.03	

CHART 30: COMPARISION OF STRESS-STRAIN DIAGRAM FOR 16MM ø BAR AND COUPLER IN COMPRESSIION:

Chart 31: COMPARISION OF STRESS-STRAIN DIAGRAM FOR 25MM ø BAR AND COUPLER IN COMPRESSIION:

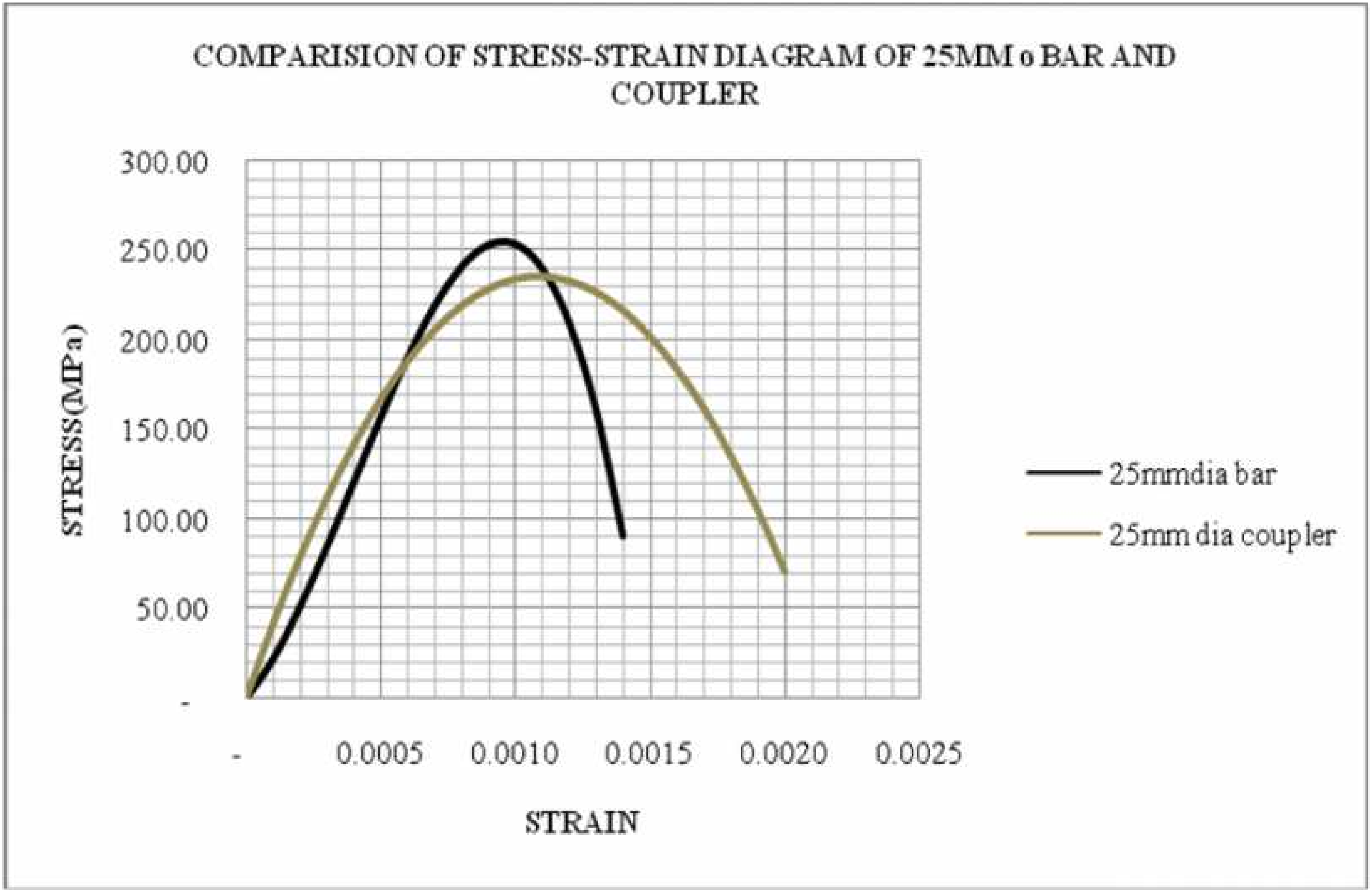


CHART 32: COMPARISION OF STRESS-STRAIN DIAGRAM FOR 32MM ø BAR AND COUPLER IN COMPRESSIION:

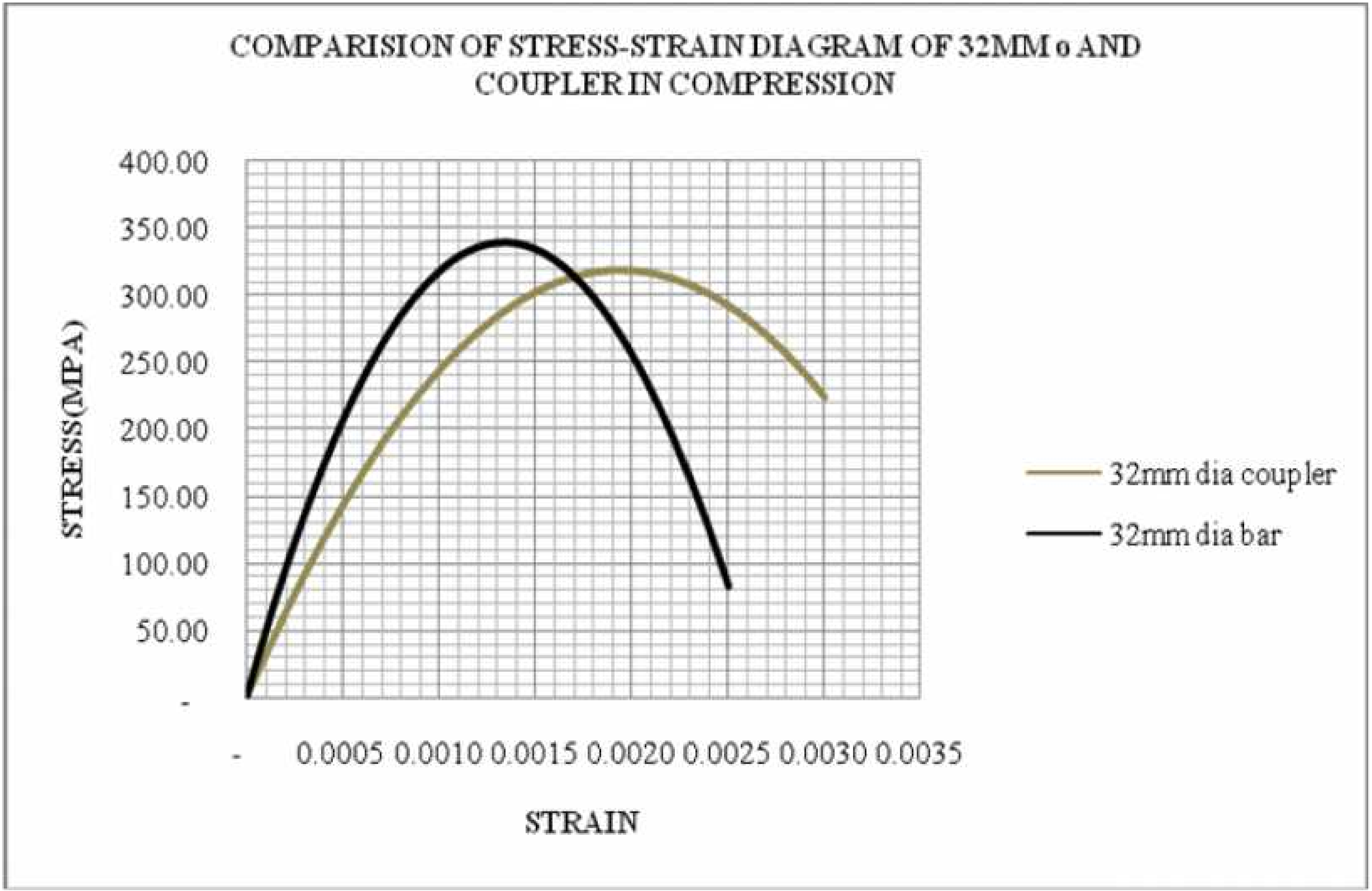


TABLE 30: COMPARISON OF 16MM ø BARS AND COUPLERS IN COMPRESSION

S.N.	Yield strength (Mpa)	Ultimate strength (Mpa)	Ratio (Ultimate/yield)	Remarks
16mm ø bar	134.54	176.53	1.31	
Coupler	173.08	209.74	1.21	
% strength achieved by coupler	128.65	118.81		

TABLE 31: COMPARISON OF 25MM ø BARS AND COUPLERS IN COMPRESSION

S.N.	Yield strength (Mpa)	Ultimate strength (Mpa)	Ratio (Ultimate/yield)	Remarks
25mm ø bar	218.87	253.50	1.16	
Coupler	166.71	235.70	1.41	
% strength achieved by coupler	76.17	92.98		

TABLE 32: COMPARISON OF 32MM ø BARS AND COUPLERS IN COMPRESSION

S.N.	Yield strength (Mpa)	Ultimate strength (Mpa)	Ratio (Ultimate/yield)	Remarks
32mm ø bar	303.13	339.31	1.12	
Coupler	284.40	319.16	1.12	
% strength achieved by coupler	93.82	94.06		

CHART 33: COMPARISION OF STRESS-STRAIN DIAGRAM FOR VARIOUS ø BAR S IN COMPRESSIION:

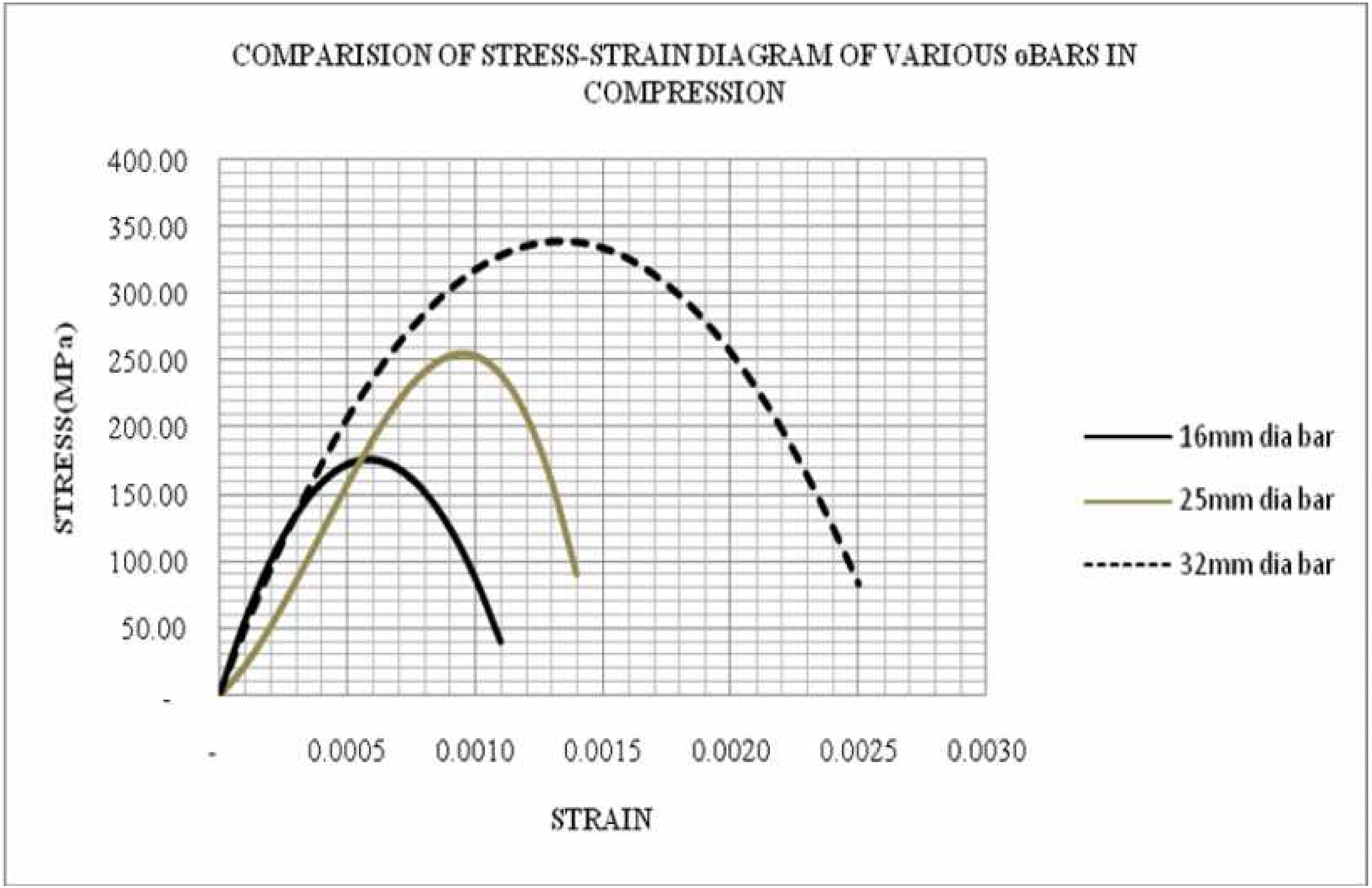


CHART 34: COMPARISION OF STRESS-STRAIN DIAGRAM FOR VARIOUS ø COUPLERS IN COMPRESSIION:

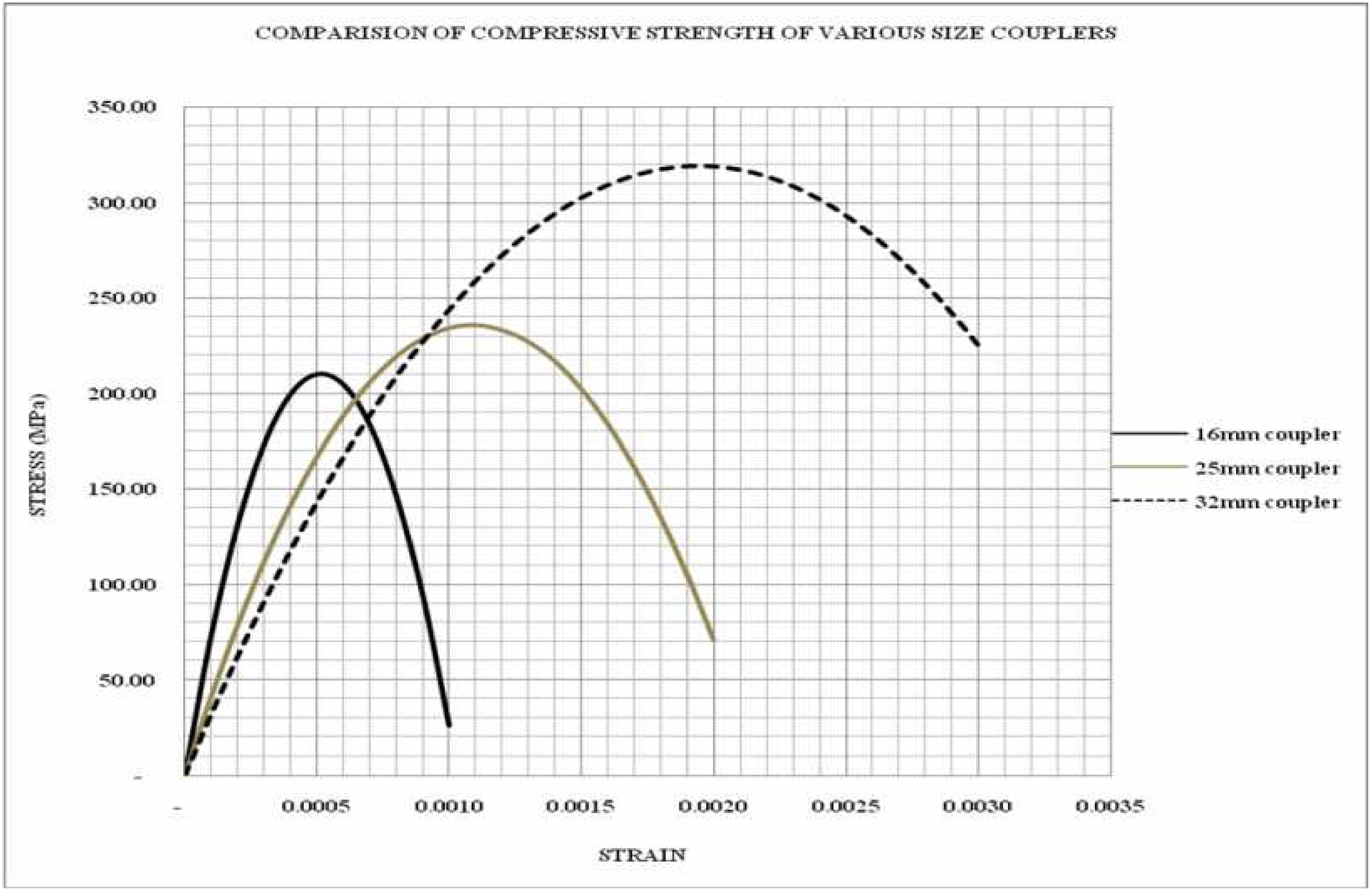


TABLE 33: COMPARISON OF VARIOUS ø BARS IN COMPRESSION

S.N.	Yield strength (Mpa)	Ultimate strength (Mpa)	Ratio (Ultimate/yield)	Remarks
16mm ø bar	134.54	176.53	1.31	
25mm ø bar	218.87	253.50	1.16	
32mm ø bar	303.13	339.31	1.12	

TABLE 34: COMPARISON OF VARIOUS ø BARS IN COMPRESSION

S.N.	Yield strength (Mpa)	Ultimate strength (Mpa)	Ratio (Ultimate/yield)	Remarks
Couplers used in16mm ø bar	173.08	209.74	1.21	
Couplers used in 25mm ø bar	166.71	235.70	1.41	
Couplers used in 32mm ø bar	284.40	319.16	1.12	

CHART 35: COMPARISION OF STRESS-STRAIN DIAGRAM FOR 16MM ø BARS IN TENSION AND COMPRESSION:

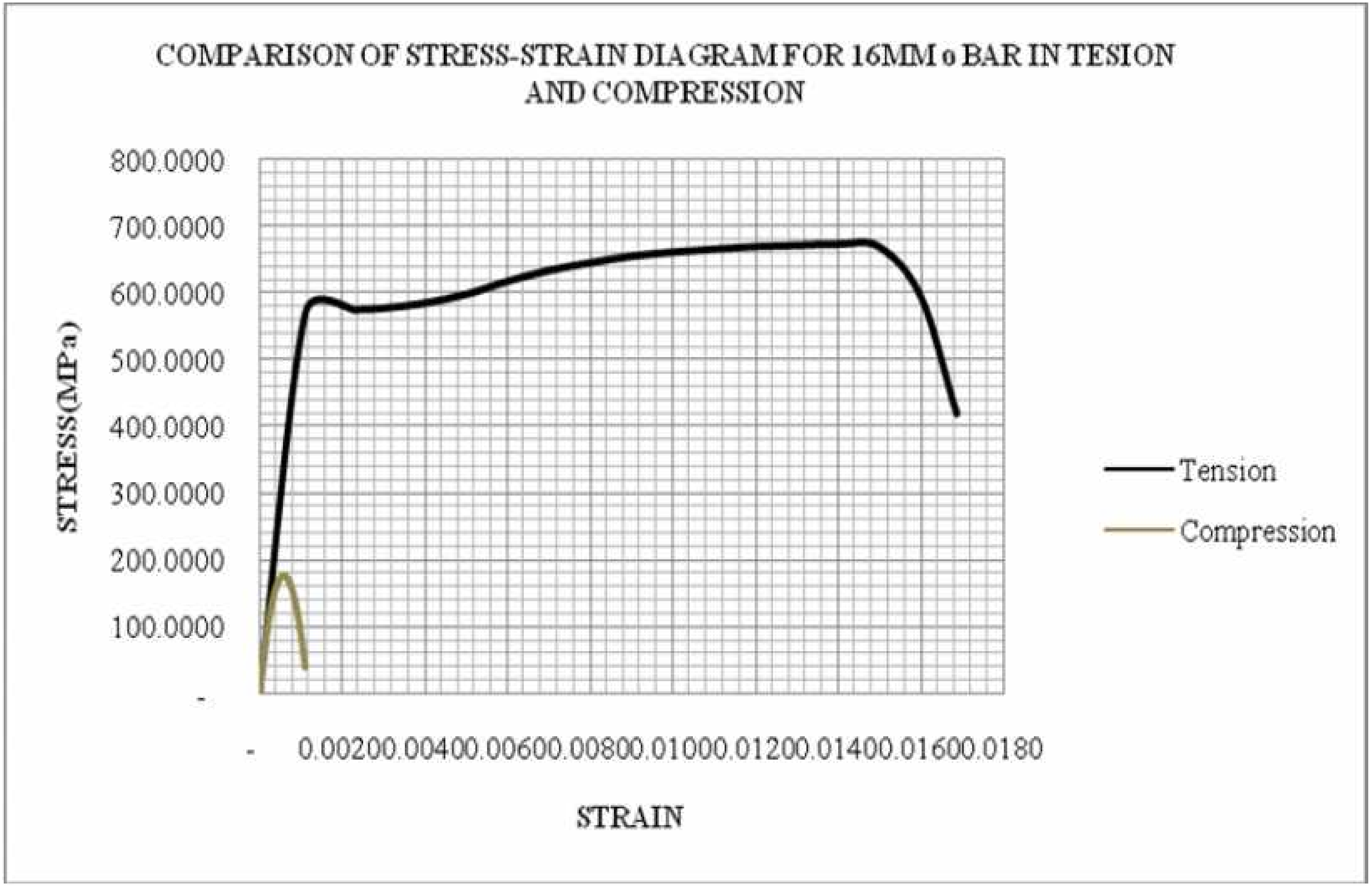


Chart 36: COMPARISION OF STRESS-STRAIN DIAGRAM FOR 25MM ø BARS IN TENSION AND COMPRESSION:

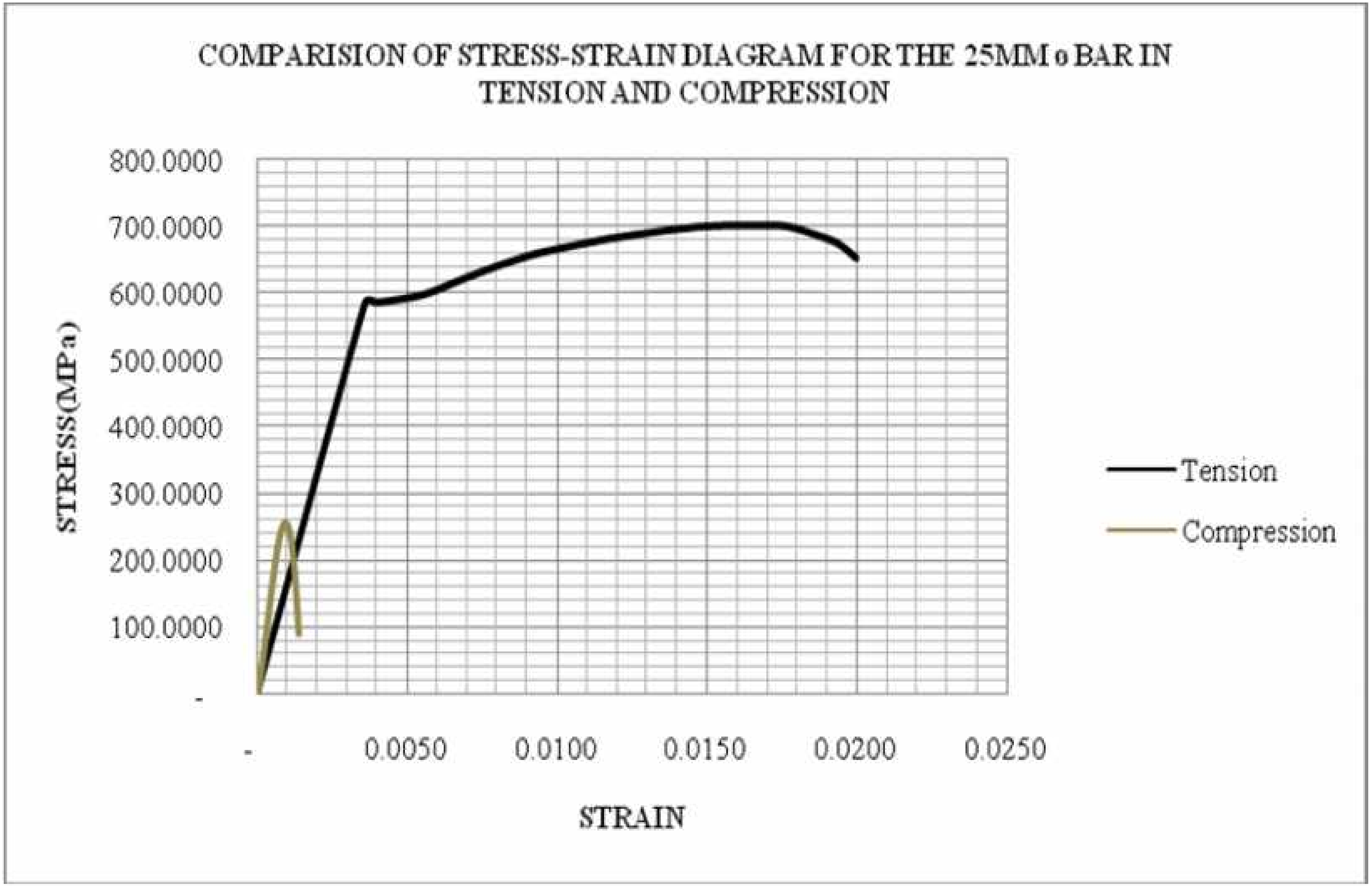


CHART 37: COMPARISION OF STRESS-STRAIN DIAGRAM FOR 32MM ø BARS IN TENSION AND COMPRESSION:

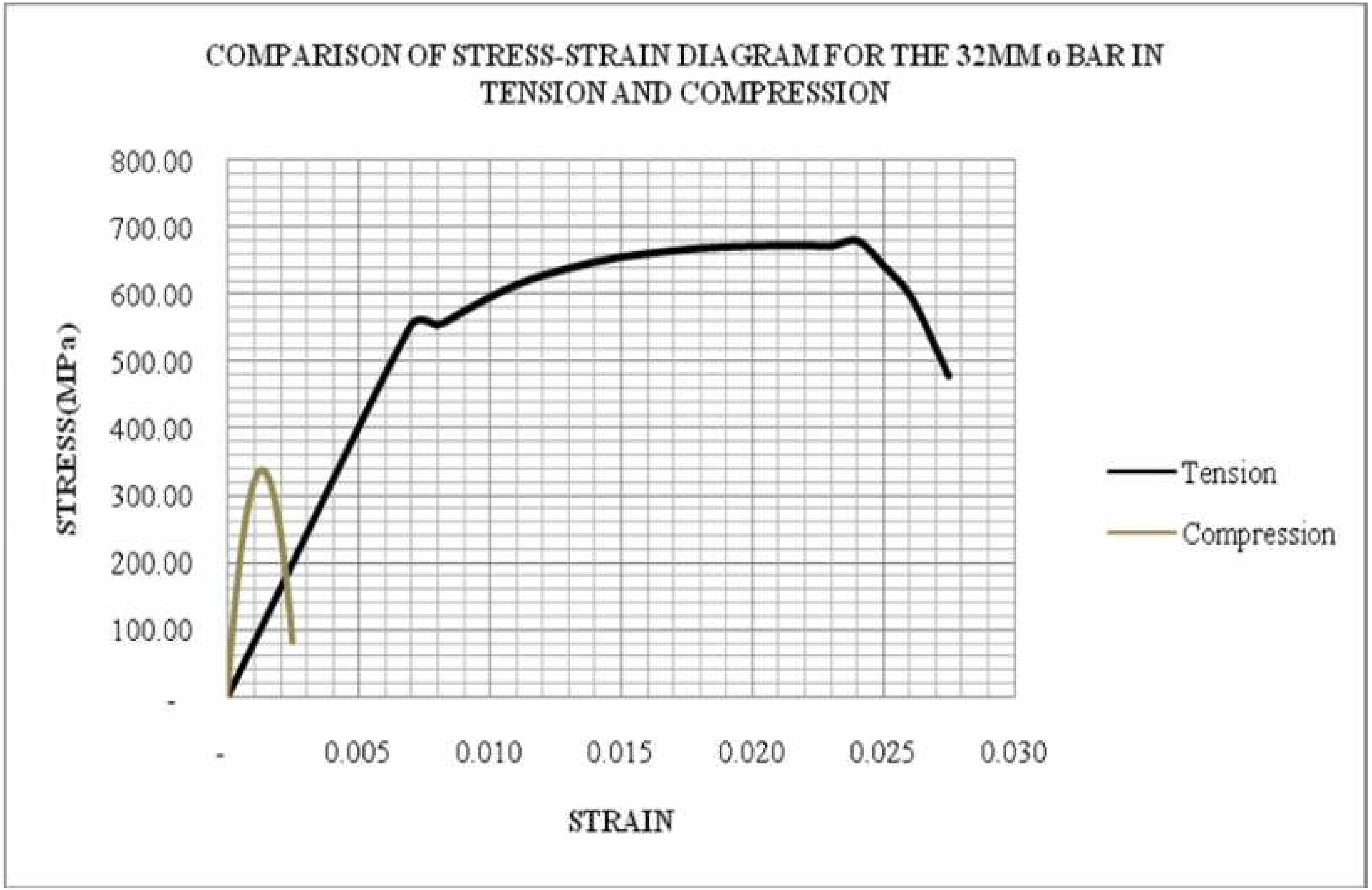


CHART 35: COMPARISION OF 16MM ø BARS IN TENSION AND COMPRESSION:

S.N.	Yield strength (Mpa)	Ultimate strength (Mpa)	Ratio (Ultimate/yield)	Remarks
Tension	573.18	674.76	1.18	
Compression	134.54	176.53	1.31	
% Difference	23.47	26.16		

CHART 36: COMPARISION OF 25MM ø BARS IN TENSION AND COMPRESSION:

S.N.	Yield strength (Mpa)	Ultimate strength (Mpa)	Ratio (Ultimate/yield)	Remarks
Tension	586.84	703.30	1.20	
Compression	218.87	253.50	1.16	
% Difference	37.30	36.04		

CHART 37: COMPARISION OF 32MM ø BARS IN TENSION AND COMPRESSION:

S.N.	Yield strength (Mpa)	Ultimate strength (Mpa)	Ratio (Ultimate/yield)	Remarks
Tension	553.34	679.08	1.23	
Compression	303.13	339.31	1.12	
% Difference	54.78	49.97		

CHART 38: COMPARISION OF STRESS-STRAIN DIAGRAM FOR COUPLERS USED IN 16MM ø BARS IN TENSION AND COMPRESSIION:

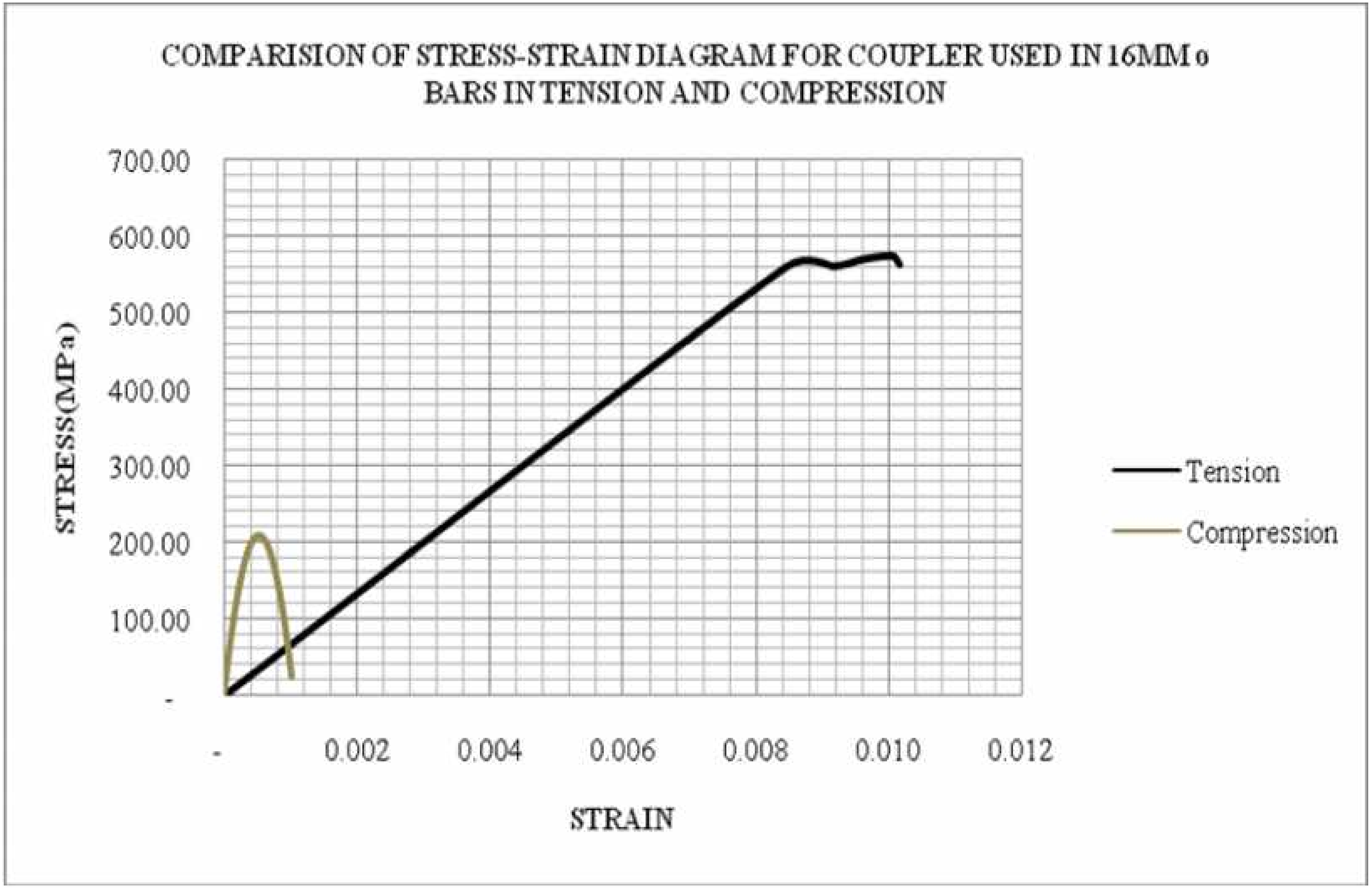


CHART 39: COMPARISION OF STRESS-STRAIN DIAGRAM FOR COUPLERS USED IN 25MM ø BARS IN TENSION AND COMPRESSIION:

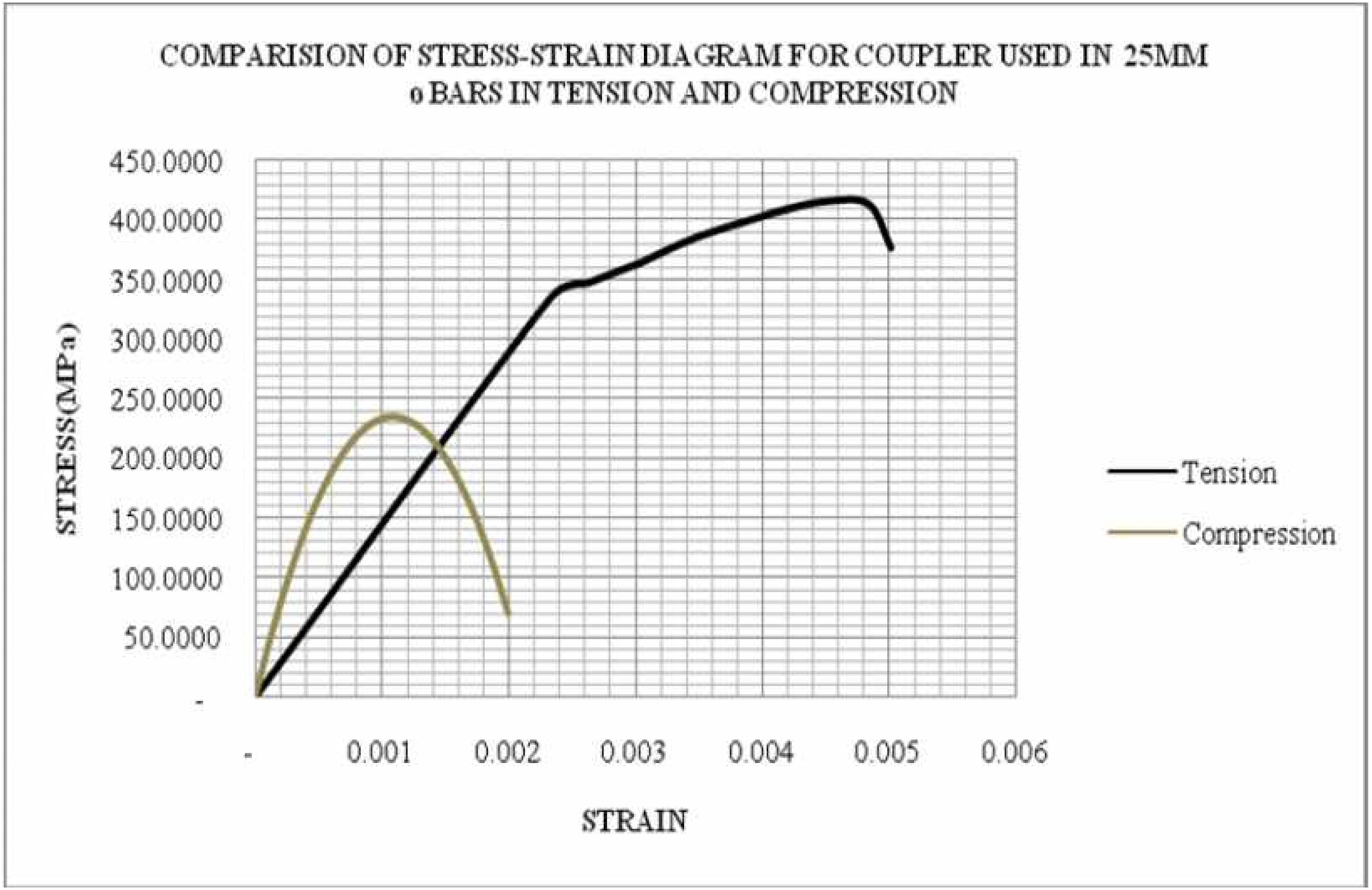


CHART 40: COMPARISION OF STRESS-STRAIN DIAGRAM FOR COUPLERS USED IN 32MM ø BARS IN TENSION AND COMPRESSION:

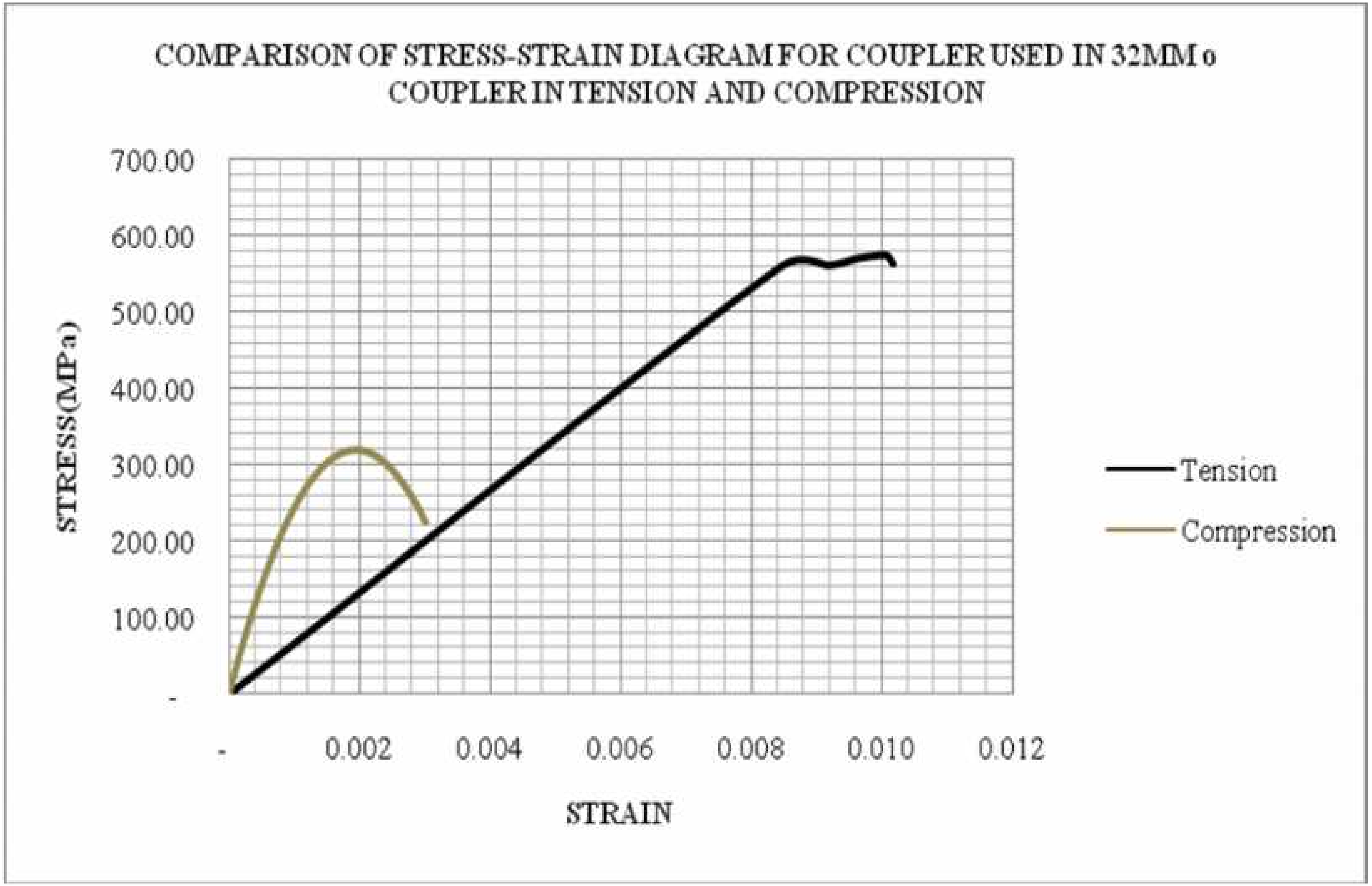


TABLE 38: COMPARISION OF COUPLERS USED IN 16MM ø BARS IN TENSION AND COMPRESSION

S.N.	Yield strength (Mpa)	Ultimate strength (Mpa)	Ratio (Ultimate/yield)	Remarks
Tension	568.06	602.79	1.06	
Compression	134.54	176.53	1.31	
% Difference	23.68	29.29		

TABLE 39: COMPARISION OF COUPLERS USED IN 25MM ø BARS IN TENSION AND COMPRESSION

S.N.	Yield strength (Mpa)	Ultimate strength (Mpa)	Ratio (Ultimate/yield)	Remarks
Tension	335.54	415.94	1.24	
Compression	166.71	235.70	1.41	
% Difference	49.68	56.67		

TABLE 40: COMPARISION OF COUPLERS USED IN 32MM ø BARS IN TENSION AND COMPRESSION

S.N.	Yield strength (Mpa)	Ultimate strength (Mpa)	Ratio (Ultimate/yield)	Remarks
Tension	560.57	574.74	1.03	
Compression	284.40	319.16	1.12	
% Difference	50.73	55.53		

TABLE 41: CHARACTERISTIC VALUES FOR YIELD STRENGTH, TENSILE STRENGTH AND RATIO:

S.N.	Standard	Norm	Grade	Yield(Mpa)	Tensile(Mpa)	Ratio(Tensile/Yield)
1	ISO	6935-2	RB-500W	500	550	1.10
2	ASTM	A615M	400	400	600	n/a

TABLE 42: COMPARISION BETWEEN THE STANDARD OF ISO AND THE LAB RESULT OF REBARS IN TENSION:

S.N.	Description	Yield(Mpa)	Tensile(Mpa)	Ratio(Tensile/Yield)
1	ISO (RB-500W)	500.00	550.00	1.10
2	16MMø BAR	573.18	674.76	1.18
3	25MMø BAR	586.84	703.30	1.20
4	32MMø BAR	553.34	679.08	1.23

TABLE 43: COMPARISION BETWEEN THE STANDARD OF ISO AND THE LAB RESULT OF COUPLERS IN TENSION:

S.N.	Description	Yield(Mpa)	Tensile(Mpa)	Ratio(Tensile/Yield)
1	ISO (RB-500W)	500.00	550.00	1.10
2	COUPLERS USED IN 16MMø BAR	568.06	602.79	1.06
3	COUPLERS USED IN 25MMø BAR	335.54	415.94	1.24
4	COUPLERS USED IN 32MMø BAR	560.57	574.74	1.03

TABLE 44: STRAIN ENERGY ABSORVED BY THE REBARS AND THE COUPLERS IN TENSION

Description	16mm	25mm	32mm
Bars	1.09E+06	2.89E+06	5.82E+06

Couplers	3.38E+05	3.37E+05	1.36E+06
% energy absorbed by coupler	30.90	11.65	23.45

TABLE 45: STRAIN ENERGY ABSORVED BY THE REBARS AND THE COUPLERS IN COMPRESSION

Description	**16mm**	**25mm**	**32mm**
Bars	1.39E+04	5.73E+04	2.27E+05
Couplers	1.39E+04	7.95E+04	2.77E+05
% energy absorbed by coupler	100.16	138.68	122.20

Appendix-IV

CHART 41: TENSILE STRENGTH OF16MM DIA BAR IN VARIOUS LAP LENGTH:

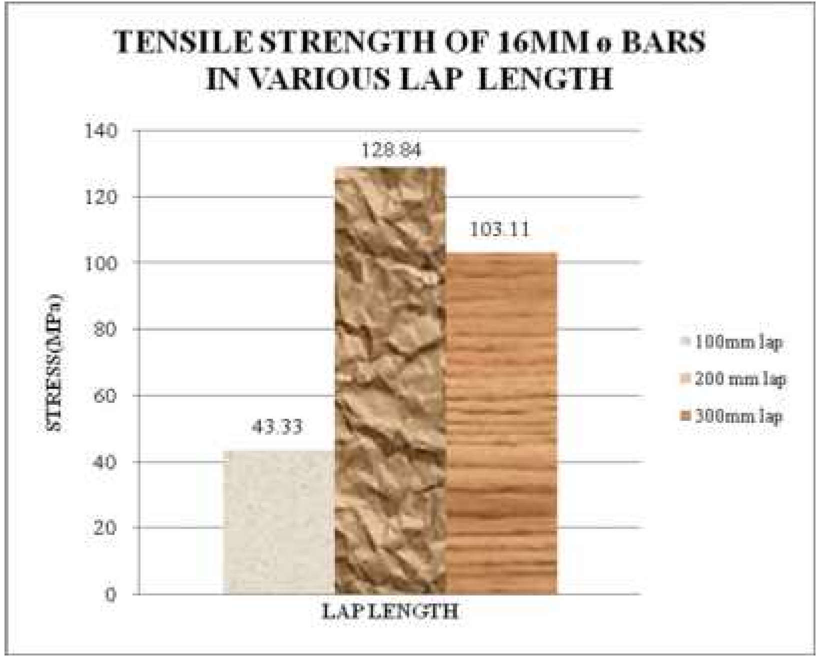


CHART 42: TENSILE STRENGTH OF 25MM DIA BAR IN VARIOUS LAP LENGTH:

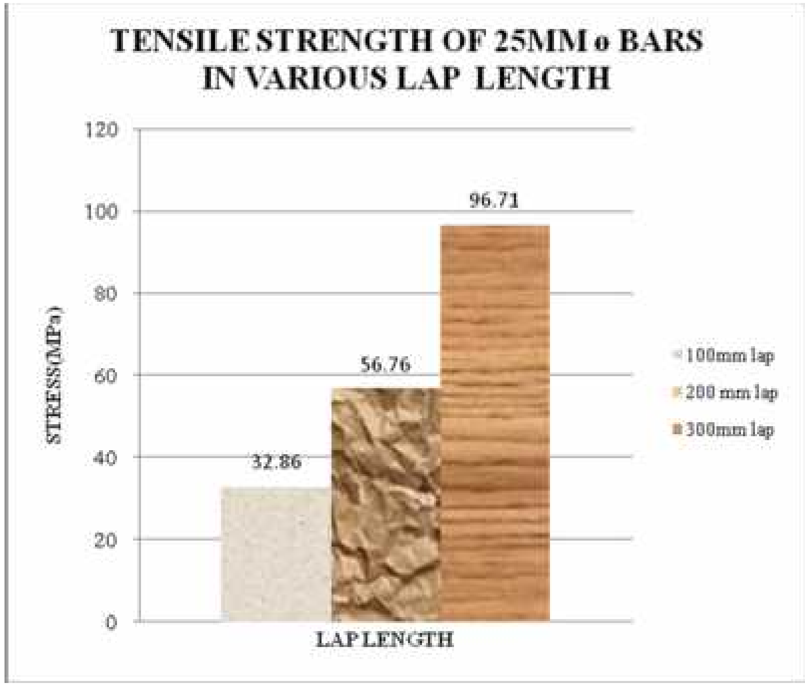


CHART 43: TENSILE STRENGTH OF 32MM DIA BAR IN VARIOUS LAP LENGTH:

CHART 44: TENSILE STRENGTH OF VARIOUS DIA BAR IN 100MM LAP LENGTH:

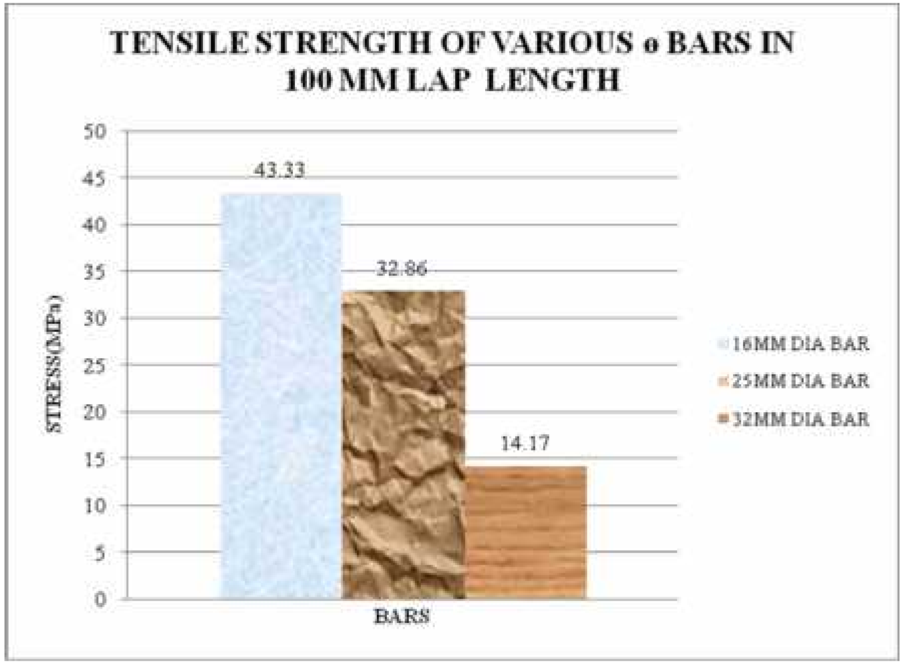


CHART 45: TENSILE STRENGTH OF VARIOUS DIA BAR IN 200MM LAP LENGTH:

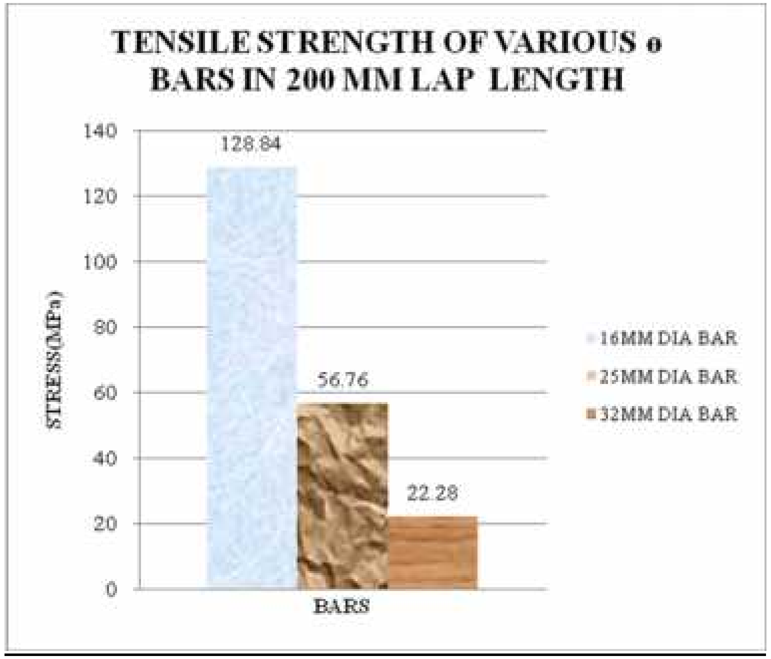


CHART 46: TENSILE STRENGTH OF VARIOUS DIA BAR IN 300MM LAP LENGTH:

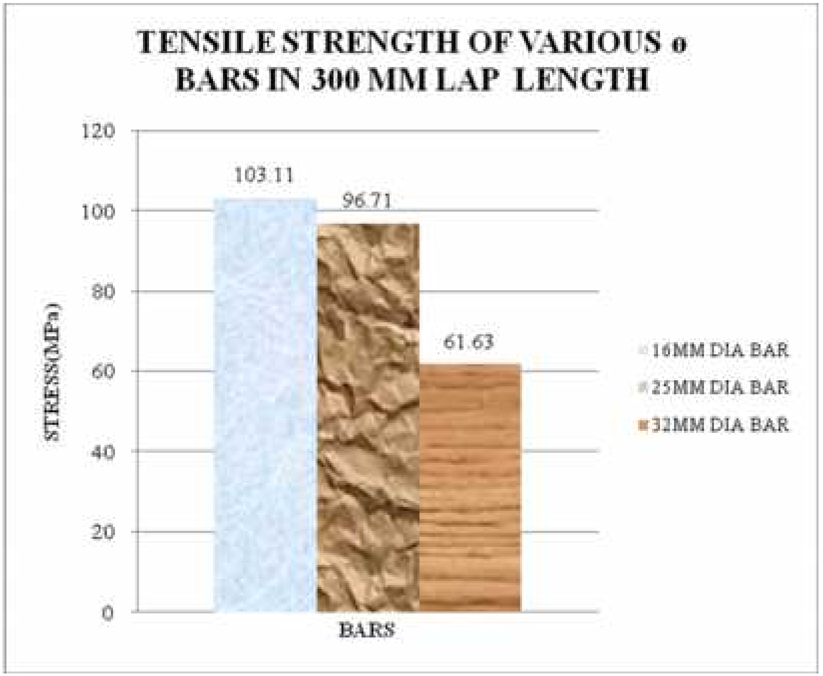


CHART 47: COMPRESSIVE STRENGTH OF 16MM DIA BAR IN VARIOUS LAP LENGTH:

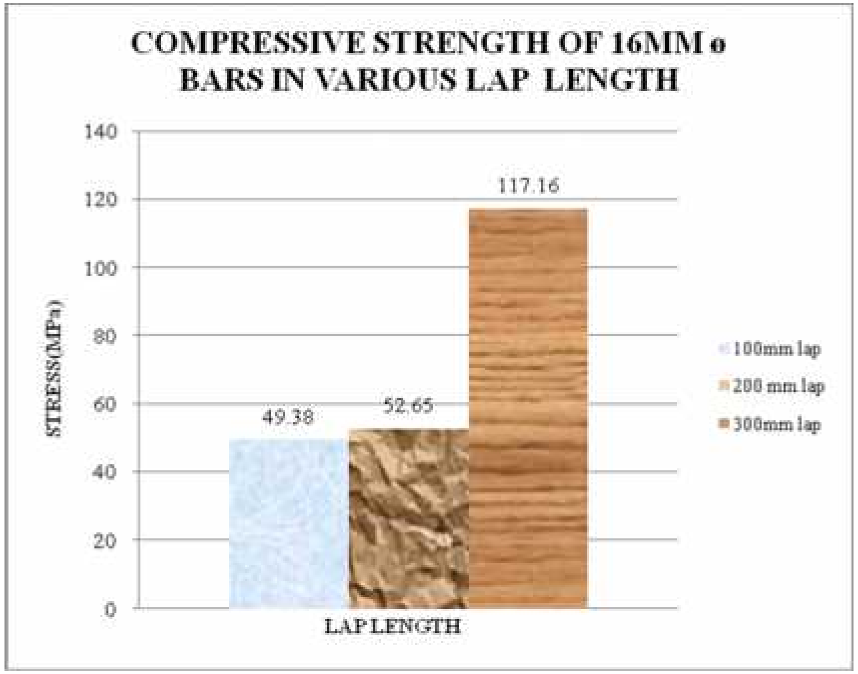


CHART 48: COMPRESSIVE STRENGTH OF 25MM DIA BAR IN VARIOUS LAP LENGTH:

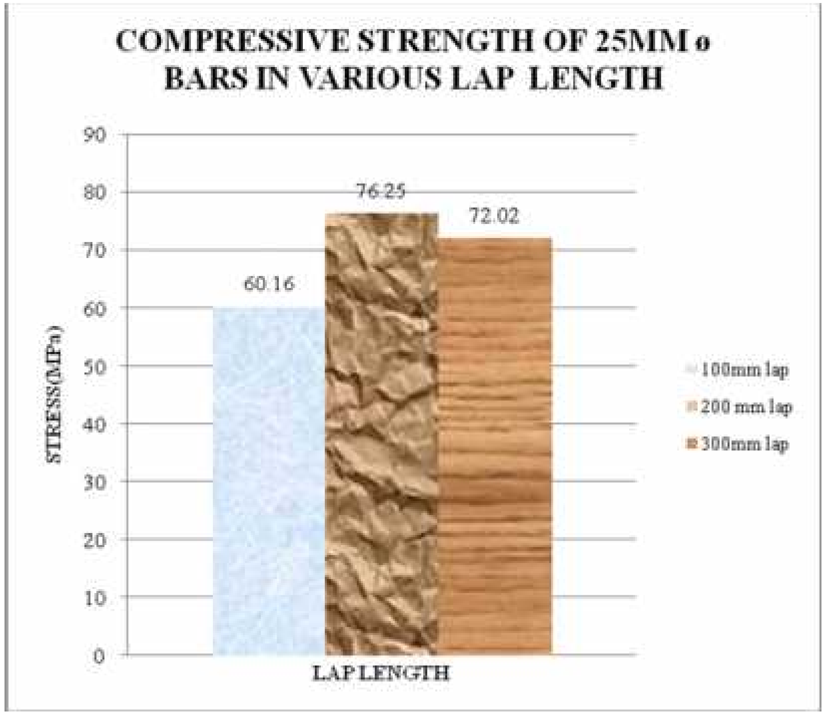


CHART 49: COMPRESSIVE STRENGTH OF 32MM DIA BAR IN VARIOUS LAP LENGTH:

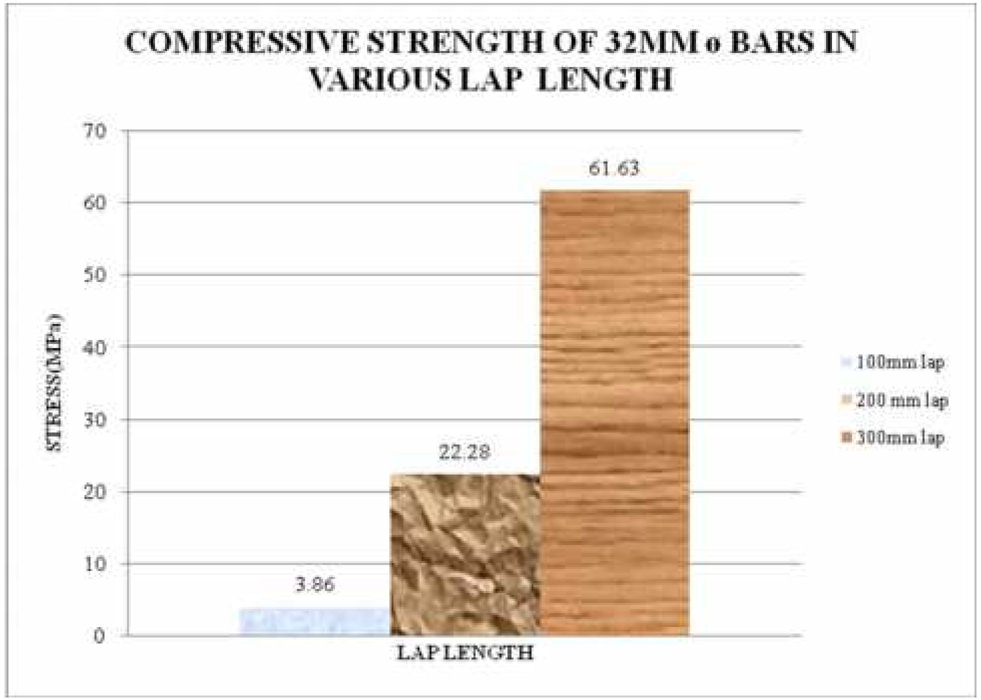


CHART 50: COMPRESSIVE STRENGTH OF VARIOUS DIA BAR IN 100MM LAP LENGTH:

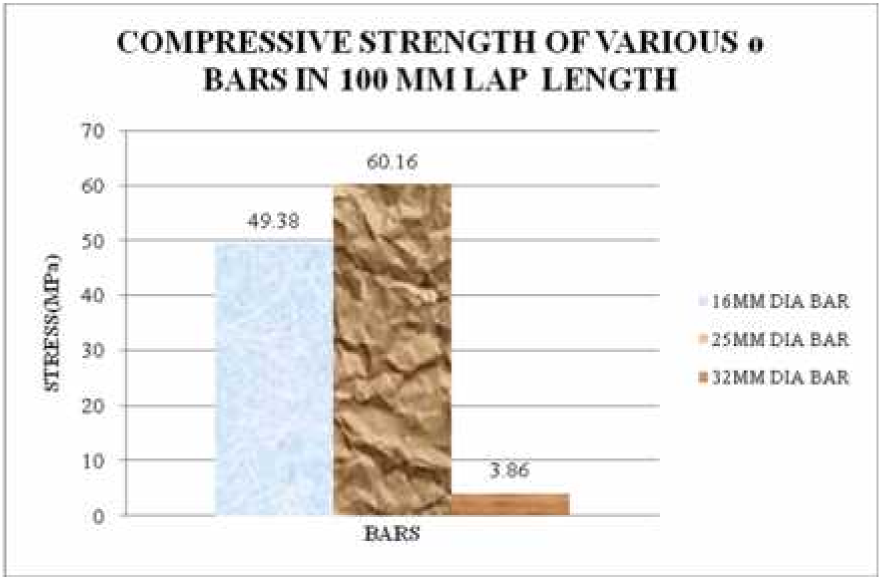


CHART 51: COMPRESSIVE STRENGTH OF VARIOUS DIA BAR IN 200MM LAP LENGTHS:

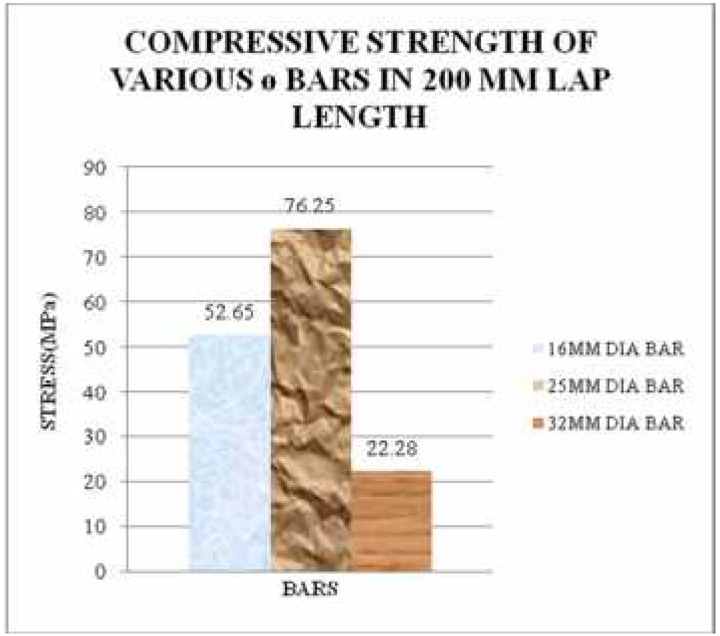


CHART 52: COMPRESSIVE STRENGTH OF VARIOUS DIA BAR IN 300MM LAP LENGTHS:

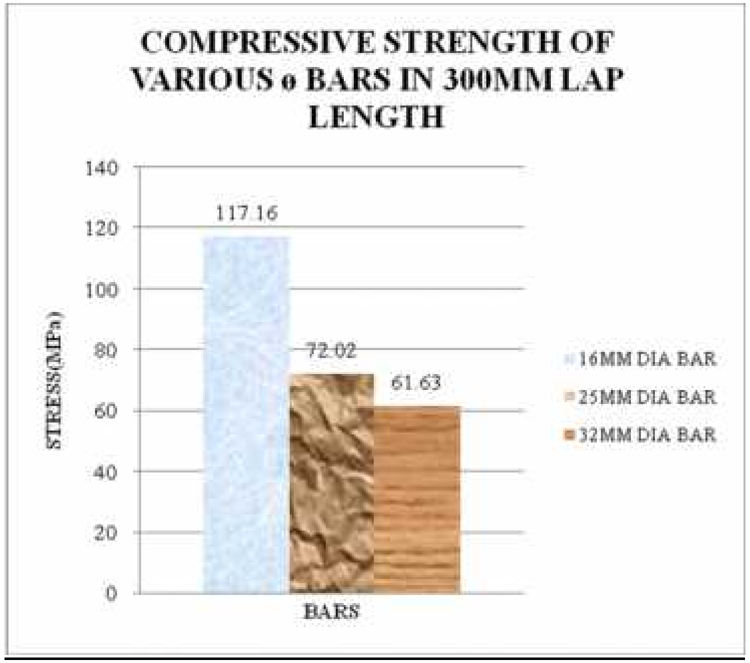
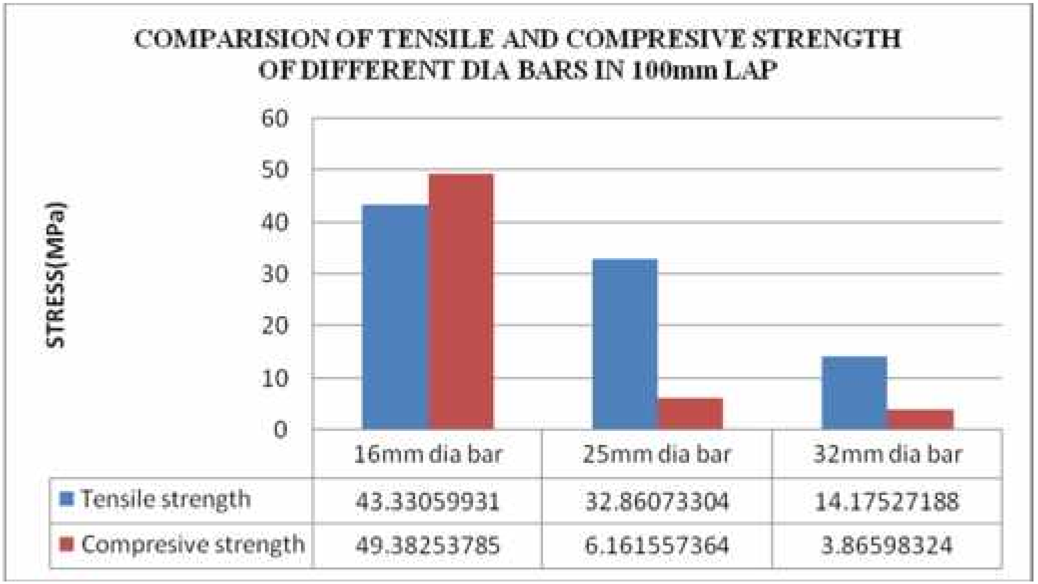
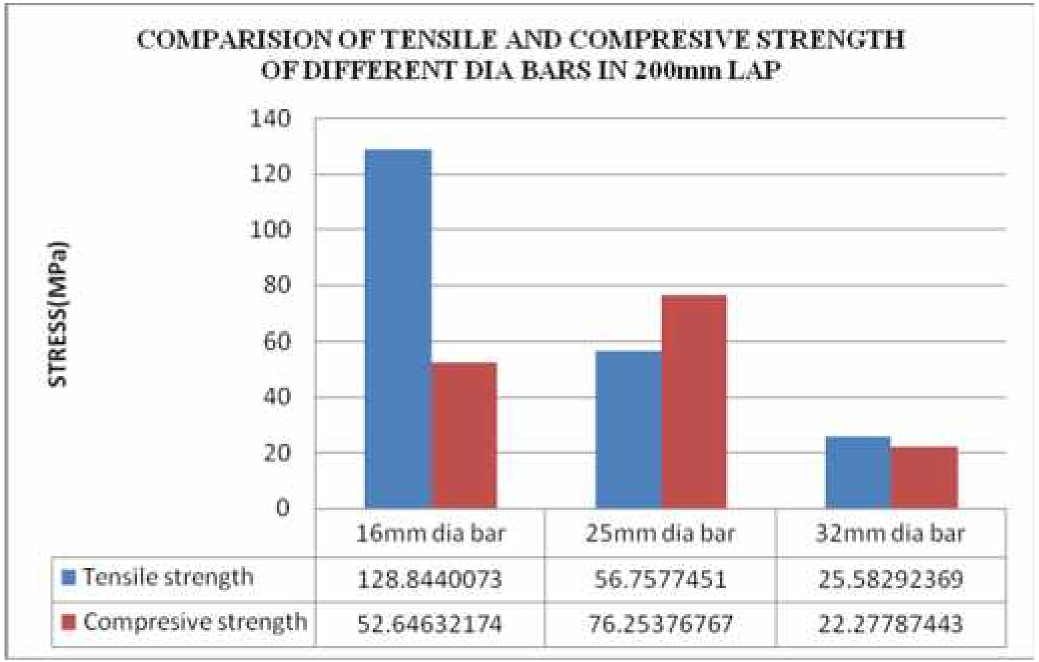


CHART 53: COMPARISION OF TENSILE AND COMPRESSIVE STRENGTH OF VARIOUS DIA BARS IN 100MM LAP LENGTH.



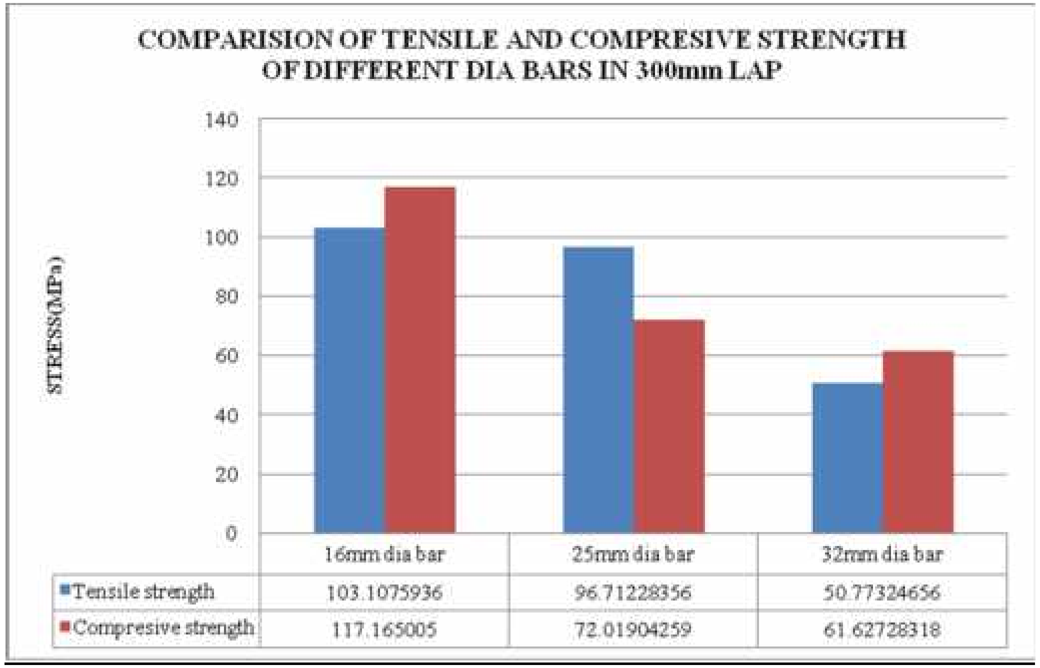
	16mm dia bar	25mm dia bar	32mm dia bar
🟦 Tensile strength	43.33059931	32.86073304	14.17527188
🟥 Compresive strength	49.38253785	6.161557364	3.86598324

CHART 54: COMPARISION OF TENSILE AND COMPRESSIVE STRENGTH OF VARIOUS DIA BARS IN 200MM LAP LENGTH.



	16mm dia bar	25mm dia bar	32mm dia bar
🟦 Tensile strength	128.8440073	56.7577451	25.58292369
🟥 Compresive strength	52.64632174	76.25376767	22.27787443

Chart 55: COMPARISION OF TENSILE AND COMPRESSIVE STRENGTH OF VARIOUS DIA BARS IN 300MM LAP LENGTH.



	16mm dia bar	25mm dia bar	32mm dia bar
🟦Tensile strength	103.1075936	96.71228356	50.77324656
🟥Compresive strength	117.165005	72.01904259	61.62728318

APPENDEX-V

LAB PHOTOGRAPHS

Photograph no.1: Specimens- different ø reinforcement bars

Photograph no.2: Specimens-couplers used in different ø bars

Photograph no.3: UTM machine

Photograph no.4: Measurement of diameter of bar

Photograph no.5: Specimen subjected to tensile test

Photograph no.6: Specimen after failure

Photograph no 7: Specimen subjected to compression test.

Photograph no 8: Specimens after tensile test.

Photograph no 9: Specimens after compression test.

Photograph no 10: Specimens-various lap length

Photograph no 11: Specimen subject to tensile test in lapping

Photograph no 12: Specimen subject to compression test in lapping

Photograph no 13: Thread slip failure and failure due to breaking of coupler

Photograph no 14: Specimens after tension and compression test.

Photograph no 15: Indexing of specimen.