

ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING



**Assessment of Locally Produced Mechanical Coupler and Traditional
Reinforcement Splice System in Building Construction**

Structural Engineering

By: Tebkew Ferede

Advisor: Dr. Asnake Adamu

July 2019

Addis Ababa

A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of
Science

The undersigned have examined the thesis entitled '**Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction**

presented by **Tebkew Ferede**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

Dr. Asnake Adamu	_____	_____
Advisor	Signature	Date
Dr. Esayas G/Yohannes	_____	_____
Internal Examiner	Signature	Date
Dr. Bedilu Habte	_____	_____
External Examiner	Signature	Date
Dr.Henok Fikre	_____	_____
Chair person	Signature	Date

UNDERTAKING

I certify that research work titled “Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

.....

Tebkew Ferede

Table of Contents	Page No.
List of Tables.....	III
List of Figures.....	IV
List of Symbols/Notation.....	V
ACKNOWLEDGEMENTs.....	VI
ABSTRACT.....	VII
CHAPTER ONE: INTRODUCTION.....	1
1.1. Background of the study	1
1.2. Statement of the problem	2
1.3. Objective and scope of the study.....	2
1.3.1. General objective of the study.....	2
1.3.2. Specific objectives of the Study	2
1.3.3. Scope of the Study.....	3
1.4. Thesis content.....	3
CHAPTER TWO: LITERATURE REIVEW	4
2.1. Introduction	4
2.2. Lap splicing reinforcement bar	4
2.2.1. Types of lap splicing reinforcement bar	5
2.2.2. Factors affecting lap splice of reinforcement	6
2.2.3. Code requirement for lap splice reinforcement	7
2.3. Weld splice reinforcement	11
2.3.1. Base reinforcement	13
2.3.2. Structural Details	13
2.3.3. Welding process	15
2.3.4. Workmanship.....	17
2.3.5. Minimum preheat and interpass temperature requirements	17
2.3.6. Code requirement for weld splice.....	17
2.4. Mechanical coupler reinforcement splice	19
2.4.1. Consideration in using mechanical reinforcement splices	20
2.4.2. Comparsion between coupler and lap reinforcement splicing.....	21
2.4.3. Static conditions.....	22

Table of Contents	Page No.
2.4.4. Experimental procedure.....	23
2.4.5. Code specification of mechanical coupler splice	25
2.4.6. Types of mechanical coupler splice.....	28
2.4.7. Mechanical coupler installation.....	39
2.4.8. Coupler selection for a construction structurale system.....	40
2.4.9. Cost comparsion	42
CHAPTER THREE: EXPERIMENTAL PROGRAM.....	43
3.1. Introduction	43
3.2. Facilities and material for experimental testing	43
3.3. Preparation of experimental specimen	46
3.4. Description of experimental procedure	48
CHAPTER FOUR: RESULTS AND DISCUSSIONS.....	51
4.1. Comparison splice type of reinforcement bar	51
4.1.1. Reinforcement bar lapping splice	51
4.1.2. Lap weld reinforcement splice	52
4.1.3. Mechanical rebar splice	52
4.2. Mechanical coupler splice procedure.....	53
4.3. Application of mechanical coupler splice in ETHIOPIA.....	59
4.4. Cost comparison splice type of reinforcement bar.....	55
4.5. Spliced reinforcement bar tensile strength test result	56
4.6. Flexural behavior and crack pattern in beam under different type of splice bars	58
4.6.1. Crack pattern for flexural beam.....	59
4.6.2. Load- deflection curve for flexural beam.....	62
CHAPTERFIVE: CONCLUSION AND RECOMMENDATION.....	78
5.1. Conclusion.....	67
5.2. Recommendation.....	67
APPENDIX-A -Splicing of reinforcement.....	72
APPENDIX-B-Concrete mix design procedure.....	80

List of Tables	page No.
Table 2. 1: Percent of reinforcement splice	9
Table 2. 2: Chemical composition welding reinforcement	13
Table 2. 3: Chemical composition for electrode	16
Table 2. 4: Tensile comparative results	25
Table 2. 5: Performance requirement for type1 and 2 splices	26
Table 2. 6: Bartec Dimensions	32
Table 2. 7: Bar X-L Dimensions	34
Table 2. 8: MBT ET Series Dimensions	36
Table 2. 9: MBT Transition Series Dimensions	37
Table 2. 10: MBT continuity series coupler Dimensions	38
Table 2. 11: MBT headed anchors Series Dimensions	39
Table 2. 12:Selecting couplers the most appropriate tasks	41
Table 3. 1: Production of coupler and reinforcement thread	44
Table 3. 2: Proportions of ingredient of concrete	45
Table 4. 1: Bar splice cost comparison	56
Table 4.2: Average comparative results of tensile test for normal and spliced rebar	57
Table 4. 3: Details of ultimate load and load at first crack	62

List of Figures

page No.

Figure 2. 1: Contact lap splicing reinforcement bar .	5
Figure 2. 2 : Non-contact lap splicing reinforcement bar.	6
Figure 2. 3: Welded splice reinforcement bar.....	12
Figure 2. 4: Welding electrode.....	16
Figure 2. 5: Welded Splice before and after Test	24
Figure 2. 6: Coupler Splice before and after Test	24
Figure 2. 7: Typical threaded coupler	29
Figure 2. 8: Threaded splice system	30
Figure 2. 9: Threading and cold swaging.....	31
Figure 2. 10: Integral threaded splice system	31
Figure 2. 11: Bartec couplers Type C	32
Figure 2. 12 :Bar X-L couplers Type C	35
Figure 2. 13:MBT Continuity Series.	38
Figure 2. 14:The Bartec type A system coupler installation phase-1.	39
Figure 2. 15:The Bartec type A system coupler installation phase-2.	40
Figure 2. 16:The Bartec type A system coupler installation phase-3.	40
Figure 3. 1: Lath machine with Internal and external threader.....	44
Figure 3. 2: Coupler internal and external reinforcement thread	45
Figure 3. 3: Reinforcement bar tensile test machine.....	46
Figure 3. 4: Slump test	47
Figure 3. 5: Beam casting sample.....	51
Figure 3. 6: Concrete compression cubes test machine	48
Figure 3. 7: Beam set up for flexural test.....	49
Figure 4. 1: Reinforcement steel congestion lap splice	51
Figure 4. 2: Lap welding splice reinforcement steel.....	52
Figure 4. 3: Mechanical splice reinforcement steel	53
Figure 4. 4: Mechanical splice reinforcement steel	54
Figure 4. 5: Welding and Coupler splice after tensile test.....	57
Figure 4. 6:Crack pattern for control beam.....	60
Figure 4. 7: Crack pattern for welding beam	60
Figure 4. 8: Crack pattern for coupler beam	61
Figure 4. 9: Crack pattern for lap beam	61
Figure 4. 10:Load vs deflection graph for coupler beam.....	63
Figure 4. 11:Load vs deflection graph for weld beam	64
Figure 4. 12:Load vs deflection graph for lap beam.....	64
Figure 4. 13:Load vs deflection graph for control beam	65
Figure 4. 14:Load vs deflection graph for all beam.....	65

LIST OF SYMBOLS/NOTATION

- As= Area of reinforcement bar
- ASTM= American standard test methods
- AWS=American welding society
- ACI=American concrete institute
- C.E=Chemical/carbon equivalent
- Cm= Centimeter
- Ø=Diameter of reinforcement bar
- EBCS= Ethiopian building code standard
- Fy= Yield strength of reinforcement bar
- ISO= International standard organization
- I.S= Indian standard
- kg/m = Kilogram per meter
- Kn= Kilonewton
- Ld =Development length of bar
- LVDT=Linear Variable Displacement Transducers
- mm=Millimeter
- mm²= Millimeter square
- MS=Mechanical splice
- MBT= Mechanical bolt coupler
- MPa=Megapascal
- N/mm²= Newton per millimeter square
- No.=Number
- OPC=Ordinate Portland cement
- Rs=Reinforcement saving
- Ψ_t=Bar location factor given in ACI Code section 12.2.4
- Ψ_e=Is an epoxy coating factor given in ACI Code section 12.2.4
- Ψ_s= Is a bar-size factor given in ACI Code
- K_{tr}= Is a transverse reinforcement factor given in ACI Code Section 12.2.3

ACKNOWLEDGEMENTS

My first thank goes to my advisor, Dr.Asnake Adamu, for his valuable advice, support and for his understanding and patience, which has made the completion of this work possible.

My acknowledgement goes to Dr. Esayas G/Youhannes and Dr.Adil Zekaria for their comments on progress reports.

My special thanks also go to the following which contributed critical for the study: Civil and Environmental Engineering Material Laboratory and the staff of Civil and Environmental Engineering Material Laboratory of Addis Ababa University, Mechanical and Industrial Engineering Laboratory of Addis Ababa University and Debre Birhan University for the production of reinforcement Weld and Mechanical coupler who have offered their technical skills throughout the labor intensive test procedures.

I would like to extend my sincere gratitude to my family and my friends for their encouragement, understanding and support throughout my study years and for their help in preparing this work.

ABSTRACT

High compression loads are well sustained by concrete elements, while tensile loads are poorly tolerated. Therefore, reinforcing steel bars of various standard sizes and lengths are used for the design of reinforced concrete structures. Manufacturing, fabrication, and transportation limitations make it impossible to provide full length continuous bars in some reinforced concrete structures. For this reason, it is often more convenient to work with shorter bar lengths, it is frequently necessary to splice bars in the field. Lap splices cause congestion at the splice locations, sometimes making their use impossible; rebar congestion making it difficult to concrete to pass through; the industry has also used mechanical coupler splice generate rebar splices. There are many types of mechanical splicing products available in the world, in Ethiopia threaded coupler use some construction project at Addis Ababa. The objective of this research is to study the speed of installation procedure among splice type, cost of splice type, the splice to be used, load-deflection and crack behavior of reinforcement concrete beams under static point load configuration of different reinforcement splice type. The methodology is experimental program, and it has been performed to investigate the research tested in point load configuration with cube test of concrete and tensile test of reinforcement splice bar type. Each beam was designed to include two bars in tension, spliced at the center of the span. A total of twelve beam specimens, specimens were grouped into four groups to investigate influences of splice type with respect to control beam, weld splice beam, lap splice beam and mechanical coupler splice beam. Each series was involved three beams tested to investigate the performance of reinforcement bar splice type. The findings of an experimental investigation, cost comparison and installation for reinforcement splice type stated under the objective with short summary. Recommendations are presented at the end.

Key words: continuous, splice, couple, bond.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

CHAPTER ONE: INTRODUCTION

1.1. Background of the study

For almost 100 years, construction practices in the building concrete structures have focused on the use of steel reinforcement to transfer tension and shear forces [25].

Splices are required when bars placed short of their required length (due to non-availability of longer bars) need to be extended. Splices are also required when the bar diameter has to be changed along the length (as is sometimes done in columns). The purpose of 'splicing' is to transfer effectively the axial force from the terminating bar to the connecting (continuing) bar with the same line of action at the junction. This invariably introduces stress concentrations in the surrounding concrete. These effects should be minimized by using proper splicing techniques; keeping the splice locations away from sections with high flexural/shear stresses; and Staggering the locations of splicing in the individual bars of a group (as, typically in a column) [20].

Splicing is generally done in one of the following three ways: Lapping of bars (lap splice), Welding of bars (lap welded splice) and mechanical connections (mechanical coupler splice). 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 the concrete to the ongoing bar [33].

Weld reinforcement splice between reinforcement bar are often made by arc-welding techniques, in which molten weld metal is fused with the parent metal of the members or component reinforcement being connected at a splice. Mechanical couplers splice available in the construction industry have come across with a solution for this complexity as it provides a greater ease in design and construction of reinforced concrete and reduce the amount of reinforcement required. The strength of a mechanical splice is independent of the concrete in which it is located and will retain its strength despite loss of cover as a result of impact damage [20].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

1.2. Statement of the problem

The use of traditional reinforcement splicing techniques for splicing reinforcement bars (lap splicing, lap welding) lead to greater congestion of reinforcement within the concrete structure.

The use of traditional reinforcement splicing techniques also increase the cost because lapping and wastage of reinforcement bar in construction during splice of reinforcement bar.

1.3. Objective and scope of the study

1.3.1. General objective of the study

This research aims at the assessment of locally produced mechanical coupler and traditional reinforcement splice system in building construction.

1.3.2. Specific objectives of the Study

This study is conducted to achieve the following specific objectives.

- I. To determine the type of mechanical coupler reinforcement bar splice that should be used in building construction.
- II. To determine mechanical coupler reinforcement bar splice installation practice or procedure in building construction.
- III. To determine the mechanical coupler reinforcement bar splice that is appropriate for a particular situation in building construction.
- IV. To compare economic difference between reinforcement bar splice for lab test beam in building construction.
- V. To study the flexural behavior and crack pattern for static point load lab test beam under different type of reinforcement bar splice in building construction.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

1.3.3. Scope of the Study

This thesis is made to address the following:

- ✚ The type of reinforcement coupler to be used for splice reinforcement bar in building construction.
- ✚ Determine the most appropriate coupler for a particular situation in structural element under building construction.
- ✚ Determine the Installation of coupler and perform economic comparison between reinforcement splice type of lab test beam.

This research is based on available analytical cost comparison and laboratory methods for performance reinforcement splice type assessment of lab beam in building construction.

1.4. Thesis content

This paper is organized in to five chapters, the details of which are arranged as follows: -

Chapter one: - Deals with introduction, which talks about the general idea and relevance of the study; it defines the objectives and scope of the study as well as organization of the thesis.

Chapter two: - Comprises of literature review, and quotes the various related works done in reinforcement splice type.

Chapter three: - Attempts to describe in detail the experimental program followed in this research study.

Chapter four: -Contains the analysis of the information gathered through the data survey, lab test and discussion of the results, based on the analysis with experimental techniques.

Chapter five: - Presents the conclusions and recommendations of the study.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

CHAPTER TWO: LITERATURE REIVIEW

2.1. Introduction

Reinforced concrete structures are designed to behave monolithically, properly designed splices of individual reinforcing bars are a key element in transmitting forces through the structure and creating a load path. The structural engineer provides location, lap length, and related information on structural drawings [38].

In building design and construction, the longitudinal connection of reinforcing bars is often needed since their length is restricted by the transportation conditions commonly not exceed 12 meters. When the length of reinforcement bar has to be extended in reinforced concrete structural member splicing is used to join two reinforcement bars to transfer the force from one bar to the joining bar, Splice is the most common way of creating a single structural entity from two rebar segments [38].

There are three methods used for splicing reinforcing bars, lap splicing, lap welded splices and mechanical coupler splice. Lap splicing, which requires the overlapping of two parallel bars and the forces are transferred from one bar to the other through bonds in concrete. Force is first transferred to the concrete through bond from one bar and then it is transferred to the other bar forming the splice through bond between it and concrete [33].

Lap welded splices which is not so common as welding have impact on the strength of bars, although low hydrogen electrode can be used for welding, Special conditions and rules are followed for welded splicing. Mechanical coupler splice is made with proprietary splice devices used to joint for reinforcement, lapping or welding splice is no longer the best method to splice reinforcement bar.

2.2. Lap splicing reinforcement bar

Lap splicing has become the traditional and predominant method used for connecting the steel reinforcing bars in Ethiopia construction industry. During design, when the available standard length of bars is less than the required length reinforcement bars need to be joined or make it longer by overlapping sufficient length to develop its full design bond stress. Reinforcing bars are spliced in situ using lap splices.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Lap splices place two bars adjacent to each other over a sufficient length to affect full development of either bar through stress transferred through the surrounding concrete [6].

Length of reinforcement bars needs to be extended; splicing is used to join two reinforcement bars for transfer the forces from one bar to the other at the location of discontinuity of bar. Lap splicing is typically overlapping reinforcing steel over a certain length. The length of the splice should be calculated according to the local building codes by a local structural engineer and specified on the project plans. In addition, where the bonding and development to be affected by the bar spacing, lap splices provide twice the number of bars within the overlap length. A group of bars, or spliced bars, will create a more adverse situation than a single bar because of the close spacing.

2.2.1. Types of lap splicing reinforcement bar

A lap splice is the predominant method used for splicing reinforcing bars, bars may be spaced apart or in contact during splice in building construction.

2.2.1.1. Contact lap splicing reinforcement bar

Contact lap splicing reinforcement bar are preferred for the practical reason that, when wired together; they are more easily secured against displacement during concrete placement are preferred because they are more secure against displacement during construction. The lapped reinforcing bars must be in contact with each other and secured together [2].

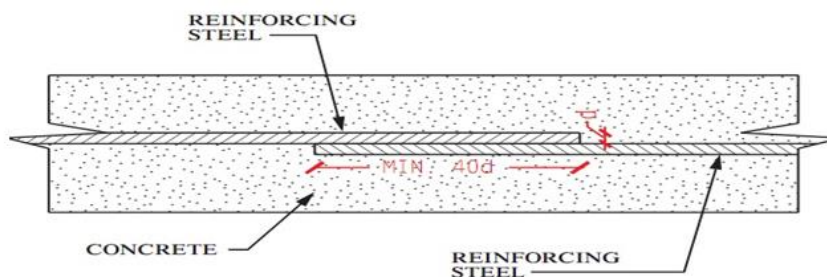


Figure 2.1: Contact lap splicing reinforcement bar [2]

2.2.1.2. Non-contact lap splicing reinforcement bar

Non-contact lap spliced bars should not be spaced too widely apart, permitting a zigzag crack in the concrete between bars, noncontact lap splices in flexural members shall not be spaced transversely farther apart than the smaller of one-fifth the required lap splice length, and 6 in [2].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

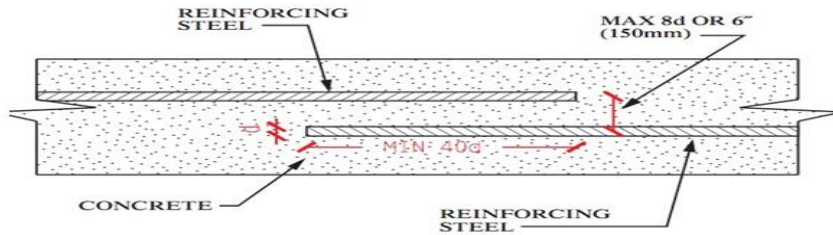


Figure 2.2 : Non-contact lap splicing reinforcement bar [2]

2.2.2. Factors affecting lap splice of reinforcement

A properly designed splicing is the key element in transmitting the forces through the reinforcement bars by creating a proper load path because splicing of reinforcement can never reproduce exactly the same effect as continuous reinforcing. Lapped splice transfers the force from one bar to another through the concrete surrounding the bars, this generate high shear stress and splitting force.

The length of a lap splice varies with concrete strength, type of concrete, the yield strength (grade) of the reinforcing bars, bar size, bar spacing, concrete cover, and the number of ties or stirrups. Splicing the reinforcement bars by laps have various imperfections such as inadequate length of laps, failure in joints, and increase in labour cost etc. Laps double the steel/concrete ratio and create problems while placing the bar and during concrete consolidation. Lap splices depend upon concrete for strength so they lack structural integrity and continuity in construction [10].

Lap splices cause congestion at the splice locations, sometimes making their use impossible; rebar congestion making it difficult to concrete to pass through; Insufficient lap splice length, to help solve these problems, the industry has also used mechanical coupler splice generate rebar splices.

The failure may result from inadequate confinement in the lap splice region or lap splices that are not long enough to develop the tensile strength of the lapped longitudinal bars. Lap splice failures are characterized by either splitting cracks of the concrete along the interface between lapped bars or shearing of the concrete between bar lugs and relative sliding of the lapped bars. Due to the stress influence of the two bars in the surrounding concrete a large development length is required for lapped splices than for anchorage. However, if the actual available length is inadequate for full development, special anchorage like hooks or bends must be provided [16].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Where the lapping of reinforcement bars has to be done in unusual circumstances such as splicing in areas of large moments or more than 50% of the bars have to be spliced, additional closely spaced spirals should be provided around the lapped bars and the length of lap should be increased [29].

Laps in reinforcement should always be staggered with center to center distances of laps should not be less than 1.3 times the required lap length of the bars. The bars to be lapped should be provided either vertically one above the other or horizontally one beside the other [28].

Lap splices are not permitted for bars larger than 36mm diameter often impractical, regardless of the bar size, in many applications. Alternatives to lap splices include lap welded splice or mechanical coupler splice [6].

The minimum lap length is not to be less than $15 \times$ the bar diameter or 300 mm. The lap length is not to be less than the tension anchorage length; If the lap is at the top of the section and the cover is less than two bar diameters the lap length is to be increased by 1.4, If the lap is at the corner of a section and the cover is less than two bar diameters the lap length is to be increased by 1.4, If both conditions apply the lap length is to be doubled [40].

2.2.3. Code requirement for lap splice reinforcement

When bars of different sizes are lap spliced in compression, the lap splice length must be the larger of the compression development length of the larger bar or the compression lap splice length of the smaller bar. When two different diameters of bars have to be lapped, the lap length should be calculated based on the diameter of the smaller bar [29].

Lap length in direct tension should be 30 times diameter of bar or $2L_d$ whichever is greater. Tension splices should be enclosed in spirals made from 6mm bars with pitch not more than 100mm. Hooks are also to be provided at the end of the tension bars. Lap length in compression should be more than 24ϕ or L_d in compression. When columns are subjected to bending, lap length may be also increased to the value in bending tension if the bar is found to be in tension [29].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Lap splice lengths are always shown on placing drawings and will be found either in the details, lap charts, or in the general notes. Lap splices in tension are classified as Type A or B, with length of lap a multiple of the tensile development length l_d calculated in accordance with 12.2.2 or 12.2.3[7].

The development length l_d used to obtain lap length should be based on f_y because the splice classifications already reflect any excess reinforcement at the splice location; therefore, the factor from 12.2.5 for excess A_s should not be used. When multiple bars located in the same plane are spliced at the same section, the clear spacing is the minimum clear distance between the adjacent splices. For splices in columns with offset bars, the clear spacing to be used. For staggered splices, the clear spacing is taken as the minimum distance between adjacent splices [5].

Tension lap splices of deformed bars and deformed wire are designated as Class A and B with the length of lap being a multiple of the tensile development length l_d . ACI Committee 318 and the ACI bond committee simplified the design expressions basic expression was developed for the development length [7].

$$l_d = \frac{3f_y \Psi_t \Psi_e \Psi_s}{40\lambda \sqrt{f'_c} \left(\frac{c_b + K_{tr}}{d_b} \right)} \dots \dots \dots \text{Eq2.1[7]}$$

The two-level splice classification (Class A and B) is intended to encourage designers to splice bars at points of minimum stress and to stagger lap splices along the length of the bars to improve behavior of critical details. The development length l_d (12.2) used in the calculation of lap length must be that for the full f_y because the splice classifications already reflect any excess reinforcement at the splice location.

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:

$$\text{Class A splice} = 1.0l_d \dots \dots \dots \text{Eq2.2[33]}$$

$$\text{Class B splice} = 1.3l_d \dots \dots \dots \text{Eq2.3[33]}$$

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Table 2.1: Percent of reinforcement splice [33]

As Provided/As Required	Maximum Percentage of As Spliced within Required Lap Length	
	50%	100%
Two or more	Class A	Class B
Less than 2	Class B	Class B

Where l_d is calculated in accordance with 12.2 to develop f_y , but without the 12 in, minimum of 12.2.1 and without the modification factor of 12.2.5. For lap splices of slab and wall reinforcement, effective clear spacing of bars being spliced at the same location is taken as the clear spacing between the spliced bars [3].

If the area of tensile reinforcement provided at the splice location is more than twice that required for strength (low tensile stress) and 1/2 or less of the total steel area is lap spliced within the required splice length, a Class A splice may be used. Both splice conditions must be satisfied, otherwise, a Class B splice must be used. In other words, if the area of reinforcement provided at the splice location is less than twice that required for strength (high tensile stress) and/or more than 1/2 of the total area is to be spliced within the lap length, Class B splice must be used [17].

The tension lap splice requirements of 12.15.1 encourage the location of splices away from regions of high tensile stress to locations where the area of steel provided is at least twice that required by analysis. When bars of different size are lap spliced in tension, splice length shall be the larger of l_d of larger bar and tension lap splice length of smaller bar [3].

2.2.3.1. Tension lap splices

Where reinforcing bars of two sizes are lap-spliced in tension, industry practice is to use the larger of the tension lap splice length for the smaller bar, or the tension development length for the larger bar. Generally, bars in tension need to be lapped over a distance of $1.3l_d$ (Class B splice, see Section 7.17.1 for l_d), unless laps are staggered or more than twice the required steel is provided (Class A splice). The designer must specify the class of tension lap splice to be used.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

The class of splice depends on the magnitude of tensile stress in the reinforcement and the percentage of total reinforcement to be lap spliced within any given splice length [16].

The connection or the splicing should be as far as possible away from the section of high stress and where several parallel bars are to be joined, the joints should be staggered. It is recommended that splices in flexural members should not be provided [16].

$$f_{bd} = 2.25\eta_1\eta_2f_{ctd} \dots\dots\dots \text{Eq2.4}$$

$$l_{b,rqd} = \left(\frac{\phi}{4}\right) \left(\frac{\sigma_{sd}}{f_{bd}}\right) \dots\dots\dots \text{Eq2.5}$$

$$l_0 = \alpha_1\alpha_2\alpha_3\alpha_5\alpha_6l_{b,rqd} \geq l_{0,min} \dots\dots\dots \text{Eq2.6[16]}$$

2.2.3.2. Compression lap splices

Reinforcing bars in compression are spliced mainly in columns, where bars are normally terminated just above each floor or every other floor. This is done partly for construction convenience, to avoid handling and supporting very long column bars, but it is also done to permit column steel area to be reduced in steeps, as loads become lighter at higher floors [36].

Compression lap splice lengths shall be $0.0005f_yd_b$, but not less than 12 in. If any of the load demand combinations is expected to introduce tension in the column reinforcement, column bars should be lapped as tension splices.

Class A splices ($1.0l_d$) are allowed if half or fewer of the bars are spliced at any section and alternate lap splices are staggered by l_d . Column lap lengths may be multiplied by 0.83 if the ties provided through the lap splice length have an effective area not less than $0.0015h_s$. Lap lengths within spiral reinforcement may be multiplied by 0.75.

Bond behavior of compression bars is not complicated by the problem of transverse tension cracking and thus compression splices do not require provisions as strict as those specified for tension splices. Compression lap splice length shall be $0.0005f_yd_b$, for f_y of 60,000 psi or less, or $(0.0009f_y - 24)d_b$ for f_y greater than 60,000 psi, but not less than 12 in. For f_c' less than 3000 psi, length of lap shall be increased by one-third [4].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Accordingly, for specified yield strengths above 60,000 psi, compression lap lengths are significantly increased, except where spiral enclosures are used (as in spiral columns) increase is about 10 percent for an increase in specified yield strength from 60,000 to 75,000 psi [4].

The lap splice length is to be computed based on the larger of the compression splice length of the smaller bar; or the compression development length of the larger bar. Lap splices are generally prohibited for No. 43mm or No. 57mm bars; however, for compression only, lap splices are permitted for No. 43mm or No. 57mm bars to No. 36mm or smaller bars [4].

Compression development lengths are considerably shorter than tension development lengths, because some force is transferred to the concrete by the bearing at the end of the bar and because there are no cracks in such an anchorage region (and hence no in-and-out bond). The basic compression-development length is the greater of [33]:

$$l_d = \left(\frac{0.02f_y}{\lambda\sqrt{f_c}} \right) db \dots\dots\dots \text{Eq2.7}$$

$$0.0003dbf_y \dots\dots\dots \text{Eq2.8[33]}$$

Where the constant 0.0003 has units of in²./lb.

The development length in compression may be reduced by multiplying by the applicable modification factors given in ACI Code Section 12.3.3 for excess reinforcement and enclosure by spirals or ties. The resulting development length shall not be less than 8 in [11].

2.3. Weld splice reinforcement

Welding is another reinforcement splice system with welded in one or both directions and rigid connections (no slip), the special instructions applicable to these bars should be followed.

Reinforcement splice between reinforcement bar are often made by arc-welding techniques, in which molten weld metal is fused with the parent metal of the members or component reinforcement being connected at a splice.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Lap splices should not be used for the bars having larger than 36 mm diameter, in that case, welding should be done, if welding is not practicable then lapping may be permitted for the bars larger than 36 mm diameter, additional spirals should be provided around the lapped bars.

Welding is often better than lapping because greater strength can be achieved, and the strength of the weld reinforcement being superior to that of the reinforcement connected. In addition, welds are more rigid than other types of load-transferring splice. In any case, the welded splices will exceed the strength of lapped with wired splices.

It will also exceed a strength level of the cast metal splices which are sufficiently strong to withstand the strength level of the reinforced concrete composite structure.

Weld reinforcement is the reinforcement in a welded joint which has been molten in the welding process and then solidified. It is usually a mixture of any filler metal and the parent metal, as well as any additions from the flux in the consumables, and will have an as-cast metallurgical structure. This structure will not be uniform because it will be diluted with more parent metal in weld runs, or passes, near the fusion boundary than away from it.

This cast structure and the thermal history requires the consumable manufacturer to devise compositions which will, as far as is possible, replicate or match the properties of the wrought parent metal but in a cast metal. As well as strength an important property to develop in the weld metal is ductility and notch toughness.

Weld metals can be obtained to match the properties of most of the parent metals which they are to be used. Welding is thus finding increasing importance for splicing concrete reinforcing bar [34].

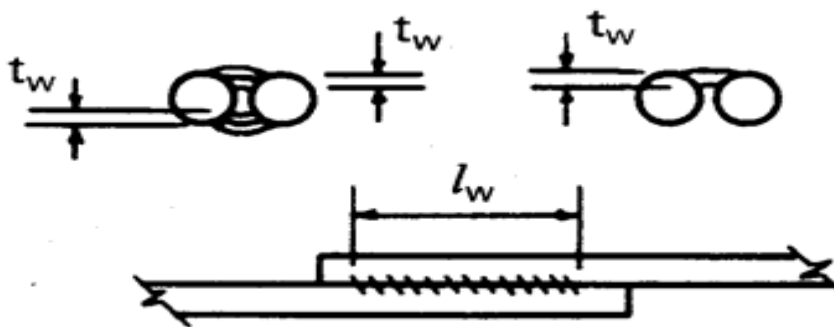


Figure 2.3: Welded splice reinforcement bar [34]

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

2.3.1. Base reinforcement

According to AWS D1.4., reinforcing steel base metal shall conform to the following requirements:

Weldability: - The term of weldability is often mentioned; a metallurgist defines weldability in terms of the chemical composition of the steel; his measure is carbon equivalent content.

A structural engineer probably thinks of weldability in terms of the strength achieved at a splice, while a welder or contractor considers it in terms of cost, welding method required and amount of preheat. Weldability as “the capacity of a metal to be welded under the fabrication conditions imposed into a specific suitably designed structure and to perform satisfactorily in the intended service.”

Source of reinforcing bars: -They are designed according to International Organization of Standardization. This part specifies technical requirements for ribbed bars designed for reinforcing in ordinary concrete structures and for non-prestressed reinforcement [31].

Grade and dimensions: -The reinforcing steel base metal used of grade RB500W, which are readily welded by conventional welding procedures: AWS D1.4-92. This reinforcing steel base metal also confirms to the requirements of ASTM specifications A615/A615M, Specification of Deformed Steel Bars for Concrete Reinforcement, of grade 500, which is approved by the “Structural Welding Code—Reinforcing Steel” [9].

Chemical composition: -The chemical composition is only provided upon request. International Organization of Standardization states that the steel used for RB500W, shall not contain quantities of the given elements higher than those specified in Table 2.2 [31].

Chemical composition-maximum values in percentage by mass:

Table 2.2: Chemical composition welding reinforcement [31]

Steel grade	C	Si	Mn	P	S	N
RB 500W	0.24	0.65	1.7	0.055	0.055	0.013

2.3.2. Structural Details

The AWS D1.4 Code includes many types of welded splices. The reinforcing bars may be welded with direct or indirect butt joint, lap joints, or T-joints. Every type is suitable for specific projects, welding processes, field conditions, and bar diameters.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

The code also provides joint design information for making direct butt splices, for making indirect butt splices, and for making lap splices.

A butt splice is a direct end-to-end splice of bars with their axis approximately in line of approximately the same size. An indirect butt splice is one in which an intermediary piece such as a steel plate or rolled angle is used with each reinforcing bar welded directly to the same piece.

For butt splices when the bars are in the horizontal position the single groove weld is most often used with a 45° to 60° included angle. Double groove welds can be made in the larger size bars. When the bars are to be welded with the axis vertical a single or double bevel groove weld is used with the flat side or horizontal side on the lower bar. On occasion, the reinforcing bar may need to be welded to other steel members and a variety of weld joints can be used [23].

Special welding procedures are usually needed for full strength welds between thick members to control the weld quality and ductility, while special inspection procedures may be required for critical welds to ensure their integrity.

These butt-welding limitations often lead to the selection of joints which use fillet weld to develop strengths equal or exceeding the specified yield strength of the reinforcing steel bars.

Joint type: -The joint type used in the project is full welded direct lap joints with bars in contact. The lap welded splice is made by overlapping the two bars alongside each other and welding together.

Fillet welds may be used to connect lapped reinforcement, as in the tension and compression reinforcement splice.

The effective area of a fillet weld shall be the effective length multiplied by the effective throat. The effective throat of a fillet weld shall be the shortest distance from the root to the face of the diagrammatic weld.

An increase in effective throat is permitted if consistent penetration beyond the root of the diagrammatic weld is demonstrated by tests using the production process and procedure variables. The minimum length of fillet welds designed on the basis of strength shall be not less than four times the nominal weld size, or else the effective size of the weld shall be considered not to exceed one quarter of its length.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

If longitudinal fillet welds are used alone in end connections of flat-bar tension members, the length of each fillet weld shall be not less than the perpendicular distance between them. Except for some special base materials, the strength of weld joints is considered to be the same as that of the base materials[37].

There are many different types of weld joints based on the style of joining base materials. The strength of welding depends on which parts of the base materials are welded and how. Consequently, performing high quality welding efficiently requires consideration of the directions of the forces that will be applied to the products after welding. The penetration in a weld joint is important to the strength, quality, and operation efficiency of welding. It must be selected in accordance with the shape of the base materials and necessary strength [23].

Fillet weld: -Fillet welds join the surfaces of two base materials positioned at an almost right angle by using triangular welds, which forms a tee joint, lap joint, or a corner joint [23].

2.3.3. Welding process

According to AWS D1.4, any welding process may be used when approved by the engineer, provided that any special qualification test requirements are met to ensure that welds satisfactory for the intended application will be obtained. Electrical welding process is utilized in this study, because it is commonly used in Ethiopia and its cost (labor and electrodes) is not expensive [31].

2.3.3.1. Welding electrode

A welder needs an electrode to generate an electric current to do arc welding. In welding, an electric current is conducted through an electrode which is used to join the parent metals. When we keep electrode tip near the parent metal electric current jumps from the electrode tip to the parent metal. The main purpose of electrodes used in welding is to create an electric arc. These electrodes can be positively charged anode or they can be negatively charged cathode [26].

The welding electrodes are classified on the basis of the electrode metal, flux coating, current used, position of welding, performance characteristics, chemistry and the mechanical properties of the weld metal [24].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

AWS stands for American Welding Society and this classification is widely used in the Merchant Marine. In this, standard electrodes for different applications are numbered such as E6010, E6011, E6013, and E7018 etc. The electrodes for electrical welding used, are ‘‘Permanent Brand Welding Electrodes’’ of $\text{Ø}3.2 \times 350$ mm with welding electrode E6013 which is a commonly used electrode on board.

E XXXX: The first character ‘‘E’’ in E6013 stands for flux covered electrode as used in Metal Manual Arc Welding.

E60XX: The next two characters indicate the minimum tensile strength. The ‘‘60’’ in E6013 indicates that the weld metal will have a minimum tensile strength of 62000 psi.

EXXIX: The fourth character indicates the different positions in which welding can be done using this electrode. In this case ‘‘1’’ in E6013 means that the welding can be done in flat, overhead, horizontal and vertical (upwards).

EXXX3: This fifth character indicates the type of flux coating used, penetration of the electrode and the type of current suitable for the electrode. In this case the ‘‘3’’ in E6013 tells that it has a rutile potassium-based flux coating. The penetration of the electrode is light and it can be used with AC and DC currents [24].



Figure 2.4: Welding electrode [24]

Here is the formulation from Harris for their E6013 rod, chemical composition in percentage by mass:

Table 2.3: Chemical composition for electrode [27]

Electrode grade	Si	Fe	Mn	P	S	C
E6013	0.18	Rem	0.45	0.014	0.012	0.08

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

2.3.4. Workmanship

Preparation of base metal: -Surfaces to be welded shall be free from fins, tears, cracks, or other defects that would adversely affect the quality or strength of weld. Surfaces to be welded, and surface adjacent to a weld, shall also be free from loose or thick scale, slag, rust, moisture, grease, epoxy coating, or other foreign material that would prevent proper welding or produce objectionable fumes.

Control of heat: -When welding is performed on bars or other structural components that are already embedded in concrete, allowance shall be made for thermal expansion of the steel to prevent sapling or cracking of the concrete or significant destruction of the bond between the concrete and the steel. The heat of welding may cause localized damage to the concrete.

Quality of welds: -Welds that do not meet quality requirements shall be repaired by removal of unacceptable portions or by re welding, whichever is applicable: Welds shall have no cracks in either the weld metal or heat-affected zone. There shall be completed fusion between weld metal and base metal and between successive passes in the weld [31].

2.3.5. Minimum preheat and interpass temperature requirements

Minimum preheat and inter-pass temperature shall be in accordance with the carbon equivalent and the size of base metal. Since the standard rebar specification ASTM A615/615M has no limit on the CE (chemical equivalent) the minimum temperature varies. Preheat and inter pass temperature shall be sufficient to prevent crack formation. Also, after welding is complete, bars shall be allowed to cool naturally to ambient temperature. Accelerated cooling is prohibited. Finally, when it is impractical to obtain chemical analysis, the carbon equivalent shall be assumed to be above 0.75%.

2.3.6. Code requirement for weld splice

Field preparation of ends by flame cutting is satisfactory. All welding of reinforcing bars shall conform to AWS D1.4. The standard rebar specifications ASTM A615, A616 and A617 do not address weldability of the steel. No limits are given in these specifications on the chemical elements that affect weldability of the steels. A key item in AWS D1.4 is carbon equivalent (C.E.). The minimum pre-heat and inter-pass temperatures specified in AWS D1.4 are based on C.E. and bar size.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Thus, as indicated in 3.5.2 and R3.5.2, when welding is required, the ASTM A615, A616 and A617 rebar specifications must be supplemented to require a report of the chemical composition to assure that the welding procedure specified is compatible with the chemistry of the bars.

The chemical composition and C.E. must be reported. By limiting C.E. to 0.55 percent, little or no preheat is required by ANSI/AWS D1.4. Thus, the engineer does not need to supplement the A706 specification when the bars are to be welded. However, before specifying ASTM A706 reinforcing bars, local availability should be investigated.

The reinforcement to be welded must be indicated on the drawings, and the welding procedure to be used must be specified. To carry out these code requirements properly, the engineer should be familiar with provisions in AWS D1.4 and the ASTM specifications for reinforcing bars. Welded splices must conform to AWS D1.4, “Structural Welding Code Reinforcing Steel.” Since splices introduce weak links into the structure, they should be located as much as possible away from points of maximum force and critical locations [1].

In a full welded splice, the bars must develop in tension at least 125 percent of the specified yield strength of the bar. AWS D1.4 allows indirect welds where the bars are not butted. Note that AWS D1.4 indicates that wherever practical, direct butt splices are preferable for No. 7 and larger bars. Use of welded splices having less than 125 percent of the specified yield strength of the bar is limited to No. 5 and smaller bars 12.14.3.5 in regions of low computed stress. Welded splices not meeting 12.14.3.2 and 12.14.3.4 are limited to No. 5 and smaller bars due to the potentially brittle nature of failure at these welds [22].

All welding of reinforcement to conform to Structural Welding Code-Reinforcing Steel. The maximum reinforcement stress used in design under the Code is the specified yield strength. To ensure sufficient strength in splices so that yielding can be achieved in a member and thus brittle failure avoided, the 25 percent increase above the specified yield strength was selected as both an adequate minimum for safety and a practicable maximum for economy [2].

A full welded splice is primarily intended for large bars (No. 19mm diameter and larger) in main members. The tensile strength requirement of 125 percent of specified yield strength is intended to provide sound welding that is also adequate for compression.

Welded splices of strength less than 125 percent of the specified yield strength of the reinforcement may be used.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

It provides a relaxation in the splice requirements where the splices are staggered and excess reinforcement area is available. The criterion of twice the computed tensile force is used to cover sections containing partial tensile splices with various percentages of total continuous steel. The usual partial tensile splice is a flare groove weld between bars and structural steel piece. A full welded splice conforming to 12.14.3.2 or 12.14.3.4 can be used without the stagger requirement instead of the lower strength welded splice [2].

2.4. Mechanical coupler reinforcement splice

Mechanical splices are a mild steel device coupling to splice two pieces of rebar when the single bar length is insufficient. Mechanical coupler splices, also known as mechanical rebar connection are used to join lengths of rebar together. Due to the growing technical challenges faced in today's construction industry, traditional methods for connecting rebar, such as lapping or welding, is no longer the best method to connect rebar. More and more construction codes are specifying a mechanical coupler because it provides better structural integrity while minimizing costs. Mechanical splices are an alternative to lap and welded splices, and many are capable of developing the full strength of the connected reinforcing bars. Mechanical splicing assures the maintaining of the continuity of the load path in the reinforcement, independent of the condition of concrete. In the mechanical splicer there is no need of additional significant lap-length since the mechanical coupler is the main force transfer mechanism. Lapped joints are dependent upon the concrete for load transfer. For this reason, any degradation in the integrity of the concrete could significantly affect the performance of the joint. The strength of a mechanical splice is independent of the concrete in which it is located and will retain its strength despite loss of cover as a result of impact damage or seismic event [38].

Comparatively, mechanical coupler splices are shorter than lap splices because of the use of coupling sleeves to connect reinforcement bars. Therefore, mechanical coupler splices are considerably suitable for repairing structures because smaller concrete area need to be removed compared with lap or weld splices. Couplers are designed to splice the bars where one bar is free to move and can be rotated [21].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

2.4.1. Consideration in using mechanical reinforcement splices

There are a number of considerations to be accounted for in specifying mechanical reinforcement splices:

2.4.1.1. Spacing and cover requirements

Minimum cover and spacing requirements for reinforcing steel and conventional lap splices apply equally to mechanical splices. Some splicing systems require additional clearances for installation, particularly if the splice requires special tools for installation.

Concrete cover must also be considered when mechanical splices (or formwork inserts serving as mechanical splices) have flanges protruding from the splice. One of the primary purposes of cover is to protect the underlying reinforcing from corrosion.

Reduced cover, in this case, translates to reduced life, as the path length for chloride ion ingress is reduced. Concrete cover also serves to inhibit splitting associated to stress transfer from the reinforcing bar to the surrounding concrete. Spacing requirements serve similar purposes with respect to inhibiting splitting along a weak plane formed by adjacent reinforcing bars.

Additionally, minimum spacing requirements are required to ensure adequate consolidation of placed concrete. Both may be affected using mechanical splices having dimensions larger than the spliced reinforcing bars [35].

2.4.1.2. Bar end preparation

Many mechanical splice systems require special preparation of the bar ends to be spliced, End bearing splices must be cut square with a tolerance ensure proper load transfer. Other end preparations include the cleaning of loose dirt, mill scale and rust particles to ensure an adequate connection with the splice or the removal of any epoxy or zinc coating. Most swaged or sleeve mechanical splices and all offset mechanical splices require no bar end preparation [35].

2.4.1.3. Zinc or epoxy coated reinforcing bar

The epoxy coating on reinforcing steel is important for providing resistance to corrosion. Many types of splices require that the coating be removed to ensure a proper splice. The epoxy coating can then be reapplied again over the top of the splice but this increases time and labor. Galvanized (zinc) coating may require removal and reapplication as well. In either case, ensuring a uniform reapplication is critical [35].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

2.4.2. Comparison between coupler and lap reinforcement splicing

Lap splicing has traditionally been the accepted form of connecting steel reinforcing bars in concrete construction. The task of gaining acceptance of reinforcing bar coupler has been made more difficult by the misconception that lap splicing is a “low cost” method of splicing [25].

Hidden Costs: -The time taken to prepare lap splices, the need for additional transverse reinforcement, the material used in forming the lap splice and the cost of rebar placement represent the hidden costs of lap splicing.

Need for an Alternative: -More demanding designs in concrete construction, new materials, hybrid concrete and steel designs and other advances in the construction industry are calling for the use of alternatives to lap splicing.

Improved Structural Integrity: -While Lap splicing systems depend on the bond between concrete and steel to transfer load, reinforcing bar coupler systems provide load path continuity independent of the condition or existence of surrounding concrete.

Improved Design Options: -Lap splicing requires the use of small diameter reinforcing bars to offset problems with rebar congestion. This often means column dimensions must be unnecessarily increased. Reinforcing bar coupler use solves this problem.

Eliminates Time-Consuming Calculations: -Compliance with current ACI and other codes requires tedious calculations, with rebar coupler, this problem does not exist.

Consistent Steel to Concrete Ratio: -Rebar couplers achieve an ideal balance of steel and concrete by eliminating unnecessary rebar while providing greater structural integrity.

Reduced Congestion: -Rebar couplers eliminate concrete pour congestion, while minimizing potential job site problems. In contrast, mechanical couplers are generally subject to extensive testing to meet the requirements of specific national standards, technical approvals or those of a state or national infrastructure owner.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

The main technical requirements for mechanical splices are: Tensile strength and ductility under static loads; this is necessary to provide a factor of safety. Limitation of permanent set slip under static loads often referred to as slip; this is necessary to limit cracking of concrete. Cyclic loading performance; necessary for structures in seismic (earthquake) regions. Fatigue performance; necessary for structures subjected to repeated loading, such as bridge decks. The first two are considered essential for building construction applications; cyclic and fatigue performance are additional requirements for specific structures. My research focusses the first technical requirements for mechanical splices under static load [25].

A margin of safety against failure of a splice is required and it is also desirable that a degree of ductility is available at the splice location in a structure.

Lack of ductility could result in little warning of possible sudden failure of the splice. Ductility is particularly important when designing couplers for use in structures subject to seismic loading, especially if their intended use is within the plastic hinge zones. As concrete structures crack, the degree of the cracking under load is controlled by reinforcement provided by the designer. Design procedures for this are well established in codes and regulations [18].

2.4.3. Static conditions

For use of mechanical coupler splice in static conditions, three categories need to be considered [39]:

2.4.3.1. Strength

The general trend for strength requirement of mechanical splice in static conditions is that the strength of the coupler must be larger than that of the spliced reinforcing bars. Most reinforced concrete design standard organizations demand an over strength factor to be multiplied to the specified yield strength of the spliced reinforcing bars for the coupler's strength requirement.

This over strength factor tends to be governed by both safeties based on reinforcing bar manufacturer's quality control and economic considerations. The coupler strength to be more than the specified ultimate strength of the spliced reinforcing bars.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

The basic logic behind the above requirements is that the spliced reinforcing bars must yield and eventually fail before the ultimate failure of mechanical connectors under loading situation, thus avoiding brittle failure of the couplers.

2.4.3.2. Serviceability Limit State

A number of reinforced concrete design standards recognize possible concrete cracking, which may arise from slip between the spliced reinforcing bar and the mechanical coupler, thus constituting a serviceability limit state. It is understood that this slip, which is a permanent or residual deformation, is a matter of manufacturer's quality control on interlock between the spliced reinforcing bar and coupler. It is also understood that the mechanical splice system tends to be more rigid once it is subjected to low stress. The reason for this is the plastic deformation due to bearing within the interlocked system of the reinforcing bar and coupler.

Serviceability limit state design in reinforced concrete under static conditions is an important aspect that structural engineers need to consider.

Appropriate crack width limits provide an aesthetically sound environment for the public as well as preventing possible corrosion occurrence in reinforcing bars.

2.4.3.3. Fatigue Loading Situation

This fatigue loading, which is a high number of cycles within the elastic stress range, can affect the mechanical splice's performance. However, assessing fatigue behavior of the mechanical coupler was beyond the scope of the research reported here.

2.4.4. Experimental procedure

The materials used in this experimental work were mechanical threaded coupler and Rebars (Fe 500). Fe 500 steel bars of diameters 16, 25, 32 mm were used for study. All the steel bars used for experimentation area of same manufacturing company. Before actual start of work all steel, specimens were tested in laboratory in order to check their stipulated property. For comparison purpose an incremental tensile load tests were carried out on welded splices as shown in Figure 2.5 and mechanical coupler splice as shown in Figure 2.6. The results were analyzed as and the feasibility of the specimens was determined based on several evaluation criteria [39].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction



Figure 2.5: Welded Splice before and after Test [39]



Figure 2.6: Coupler Splice before and after Test [39]

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Average comparative results of 16 mm, 25 mm and 32 mm diameter rebar for splicing

Table 2.4: Tensile comparative results [39]

Samples: I, II and III	Normal Bars (I, II & III)			Coupled Bars (I, II & III)			Welded Bars (I, II & III)		
	16-TS	25-TS	32-TS	16-TS	25-TS	32-TS	16-TS	25-TS	32-TS
Identification Mark									
Mass/meter (kg/m)	1.54	3.766	6.31	1.54	3.766	6.31	1.54	3.766	6.31
a) Yield stress Obtained(N/mm ²)	584	655	579	552	554	541	529	534	526
b) Yield stress Standard as per I.S. 1786(N/mm ²)	> 500								
a) Ultimate stress Obtained (N/mm ²)	698	741	676	632	657	655	602	604	621
b) Ultimate stress Standard as per I. S. 1786(N/mm ²)	> 545								

2.4.5. Code specification of mechanical coupler splice

While there are a number of different codes around the world for coupler manufacture and joint threading, some of the most common and relevant ones are listed below with a brief summary of their requirements. The most commonly referenced code for mechanical couplers, it is purely a performance based on code and categorizes splicing into two groups – Type 1 and Type 2. Type 1 splices are used when there is no expectation of inelastic deformation or elevated tensile stress due to seismic loading. Type 2 splices are those that have been demonstrated through accepted testing procedures to be able to develop the specified tensile strength of the reinforcing bars for resistance to increased tensile forces that may be expected from seismic loading. Thus, a Type 2 splice may be considered a “seismic splice” [7].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Table 2.5: Performance requirement for type1 and 2 splices [35]

	Relevant section in ACI 318-05	Reinforcing bar grade		
		A706	A615	
			Grade40	Grade 60
Type1 mechanical splices	12.14.3	1.25f _y >80ksi (550MPa)	1.25f _y	1.25f _y
Type2 mechanical splices	21.2.6	1.25f _y	60ksi (420MPa)	90ksi (620MPa)

A Type 1 joint is required to achieve 1.25F_y as a minimum while Type 2 is required to comply with 1.25F_y requirement and also meet the specified tensile strength of the rebar. The ACI code accepts steel which has a specified minimum tensile strength. For example, for Fe500, while F_y=500 N/mm², the ultimate stress expected from the same is at least 700 N/mm².

In view of this, the code can be read as such, For Type 1, the joint is expected to have a tensile strength not less than 625 N/mm² while for Type 2, acceptance is at 700N/mm². Let us interpret the code as per its actual purpose.

Type 1 was a reduction allowance from the ultimate tensile stress of the rebar for the joint; however, the code also restricted the location of its use, mainly in the zones where the stress on the member would be significantly lesser i.e. lap zones. If the joint could sustain the ultimate design requirement, it could be used freely anywhere in the structure [7].

This code specifies various types of mechanical splices and provides recommendations for usage of splicing systems and strength requirements. Acceptance of the results has been left to the structural consultant [28].

While the British code has lower acceptance criteria as compared to the ACI code, it specifies tensile testing and Slip Test for the joint for acceptance of the sample [13].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

The BS 5400 is a code for design of concrete bridges and details requirements for lapping bars, welding, providing sleeve and for taper and parallel threading of rebar. Staggering of the re-bars has been recommended along with usage of such connections in lower stress zones. Tests include tensile stress, slip test and fatigue tests [14].

The ASME Code provides a list of different types of splices and their acceptance criteria. The tests which are required to be carried out include tensile tests and cyclic tests. Acceptance in tensile test is defined as being no less than 90% of the actual tensile strength of the reinforcement bar being tested and not less than the minimum specified strength.

The individual splices also have to conform to the 125% of the specified minimum yield strength requirements. This condition for a rebar complying with ACI 318 requirements would mean that the joint is expected to have at least $0.9 \times 700 = 630 \text{N/mm}^2$ which is not less than its specified minimum of 625N/mm^2 . The cyclic test prescribed is for 100 cycles of stress variation from 5% to 90% of the specified minimum yield stress. The tests are meant for design confirmation of the coupler and required to be repeated if the coupler parameters such as size, material, cross-section area are changed or if the coupler is redesigned for higher grade of rebar [12].

The IS 16172:2014 is a manufacturers code for production of couplers only and is not meant for site execution. It is recommended that the coupler be designed for Fe550 grade as a standard.

The performance of the mechanical splice is to be determined with reference to IS 1786:2008 and IS 456:2000.

The drawback of this classification is that even if the coupler is designed for a higher grade of rebar and has sufficient capacity, the cyclic and tensile tests will not reflect the site conditions [30]. The only tests recommended for acceptance on projects as per this code are static tensile tests which are considered as per IS 1786:2008 code. For example, while a Fe500 rebar breaking at a stress of 580N/mm^2 would be rejected as per the ACI code criteria of 625N/mm^2 , the same sample would be considered acceptable as per the IS 1786 requirement of 545N/mm^2 .

This will facilitate the use of relatively sub-standard rebar for preparation of joints effectively reducing the factor of safety for the joint. In such a case, it is up to the site and consultant to ensure that such a practice is not promoted [25].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

2.4.6. Types of mechanical coupler splice

There are many types of mechanical splicing products available in the world, in Ethiopia threaded coupler use some construction project at Addis Ababa.

In this discussion they have been categorized as in-line splices, in which the centerline of each spliced bar coincides; and offset splices, where the centerlines have an eccentricity [39].

Mechanical coupler splice mainly two type that are threaded and non-threaded coupler splice in construction industry.

2.4.6.1. Threaded Couplers

Tapered Threaded Couplers: - This type of tapered couplers is fitted to one end of the threaded rebar and the adjoining rebar is connected and tightened by means of a calibrated torque wrench. Tapering the cut-thread system helps make good alignment and quick joining of bars. Tapering also helps reduce stress concentration in the threaded regions.

Roll Threaded Couplers: In this type, the bars that are to be connected is pressed by a set of rollers, these pressed ends are connected by a coupler with matching and parallel threads [39].

2.4.6.1.1. Compression only mechanical splices or end bearing splices

As it may be noticed from its name, this type of splice can resist compression stress merely. The compressive stress is transferred by vertical bearing from one bar to another one. Compression only mechanical splices can be used when tension stress is not occurred.

Therefore, if this condition cannot be guaranteed, then it is advised to avoid the use of compression only mechanical splices for reinforcement bars. Steel filled coupling sleeve is the most commonly used examples of end bearing splices [39].

2.4.6.1.2. Tension and compression mechanical splices

This type of mechanical splice can resist tension and compression stress. There are sizable numbers of commercially manufactured tension and compression mechanical splices. Tension and compression mechanical splices types, designated bar sizes to be spliced by each splice type, the grade of the steel bar which is spliced using certain type of tension and compression mechanical splice, and installation condition of each mechanical splices [19].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

2.4.6.1.3. Dowel bar mechanical splices

Dowel bar mechanical splices are flanged couplers that can resist tension and compression forces, this splice is nailed to the end or sides of the formworks through holes created in the flange. The connection between reinforcement bars and the splice is through internal threads of the splice. Threaded rebar or dowel is screwed into the coupler, and the flange plate is secured to the bulkhead form. When the forms have been stripped and steel is being set for the next placement of concrete, the connecting threaded bar or dowel is inserted into the coupler [19].

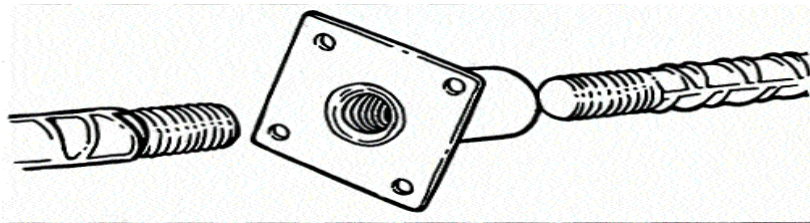


Figure 2.7: Typical threaded coupler [19]

2.4.6.1.4. Metal filled sleeve

Reinforcing bars are placed end to end in the metal sleeve, and a molten metal filler is introduced through the tap hole. The filler material flows between the bars and the sleeve, solidifying in the deformations of the rebar and in the internal ribs of the sleeve, forming a mechanical interlock.

Bar ends must be clean and dry but require no special preparation.

This method has the advantage of back fit capabilities; that is, it is able to correct oversights, to promptly meet schedule changes, and to make repairs following destructive quality control procedures. Metal-filled sleeve can be used for either tension or compression splice. Heated metal filler flows between rebar deformations and internal ribs of the sleeve, creating a mechanical interlock [19].

2.4.6.1.5. Grout or mortar-filled sleeve

Grout splice system using grout or mortar filler works much the same way as the metal-filled sleeve, by mechanical interlock. The sleeve is shaped like two cutoff cones butted together. A proprietary high strength grout pumped into the sleeve using a low-pressure grout pump forms an interlock between rebar deformations and the internal ribs of the sleeve.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Some disadvantages of this system are its bulkiness, special grout requirements, lack of heat resistance, and chemical reaction concerns. Setting time for the grout may be from 2 to 4 hours or more, depending on temperature. However, the system has special advantages for assembling precast concrete units without closure pours or formwork. Grout or mortar-filled splices have special applicability for precast concrete connections [39].

2.4.6.1.6. Threaded couplers mechanical splice

The threaded with an ordinary system is to dress the ends of the rebar before cutting or rolling the threads, thereby reducing nominal bar area and lowering load capacity. There is little or no strength difference between cut and rolled threads of the same size. Rebar ends may generally be threaded either in the fabricator's shop or in the field.

Threaded sleeve for special bars has internal threads to match the rolled thread-like bar deformations. Threaded bar ends must be protected against damage during shipping and handling until the splices are completed [19].

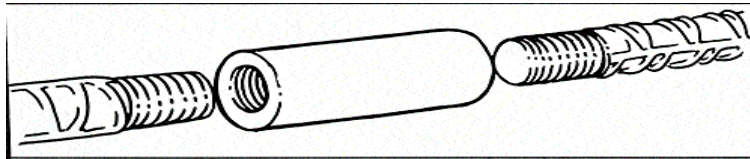


Figure 2.8: Threaded splice system [19]

2.4.6.1.7. Swaged and threaded couplers

The splice makes use of both threading and swaging and does not reduce the net area of bars being spliced. An internally threaded coupler is cold forged by octagonal dies onto the end of a rebar. The end of a second bar a pre-threaded male adapter matching the internal threads of the coupler is swaged into place. The net area through the thread region equals or exceeds the nominal bar diameter and torquing is not needed. This swaging may be done in either shop or field, but not on the bar in place in the structure. An internally threaded coupler is cold forged onto the end of one rebar. On the end of the second rebar, a pre-threaded male adapter matching the internal threads of the coupler is also swaged into place. The two bars are then simply twisted together [39].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

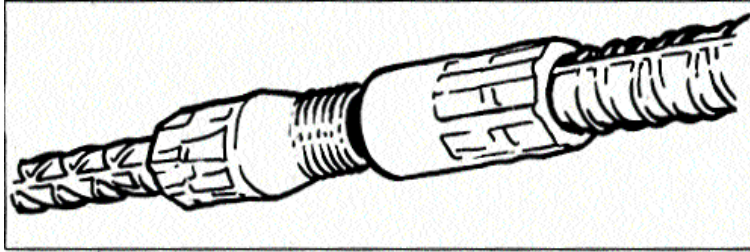


Figure 2.9: Threading and cold swaging [39]

Integral threaded splice system achieves a doweled splice at construction joints with only one connection. It is manufactured from two pieces of rebar, one forged with a barrel tapped with standard coarse threads and finished with an integral flange. The end of the adjoining piece of dowel is enlarged to match by upset forging and roll threading [19].

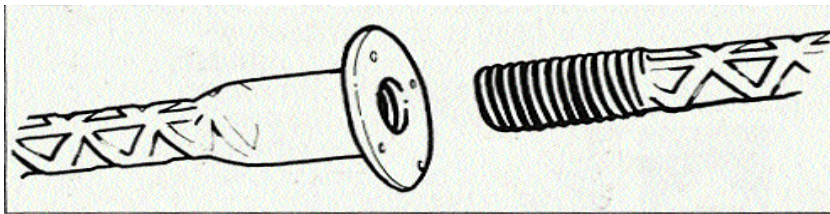


Figure 2.10: Integral threaded splice system [19]

2.4.6.1.8. Bartec mechanical coupler splice

The end of each bar to be joined is cut square and enlarged by cold forging. This increases the core diameter of the bar to ensure that the joint is stronger than the bar. Parallel metric threads are cut onto the enlarged ends. The threaded ends of the bars are protected by an external plastic sheath. Couplers, which are usually supplied attached to the bar, have their internal threads protected by an internal plastic end cap [20].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Table 2.6: Bartec Dimensions [20]

Bar diameter	12	16	20	25	28	32	36	40	50
External Dia.	21	26	32	40	45	50	57	62	77
Coupler Length	32	40	48	60	66	72	84	90	112
Thread Size	M16	M20	M24	M30	M33	M36	M42	M45	M56
Thread Pitch	2.0	2.5	3.0	3.5	3.5	3.0/4.0 *	4.5	4.5	5.5
Weight (kg)	0.04	0.09	0.16	0.32	0.43	0.58	0.87	1.13	2.17
Part No Type A	BT12/ A	BT16/ A	BT2 0/A	BT25/ A	BT28/ A	BT32/ A	BT36/ A	BT40/ A	BT5 0/A
Part No Type B	BT12/ B	BT16/ B	BT2 0/B	BT25/ B	BT28/ B	BT32/ B	BT36/ B	BT40/ B	BT5 0/B
Part No Type C	-	BT16/ C	BT2 0/C	BT25/ C	BT28/ C	BT32/ C	BT36/ C	BT40/ C	BT5 0/C

Bartec Type A:-The Bartec Type A system utilizes internally threaded couplers with a single right-hand thread and is suitable for applications where the continuation bar can be rotated. The ends of the bars are upset and threaded for half the length of the coupler.

Bartec Type B:-The Bartec Type B uses the same coupler as the Type A system, but one bar is threaded for a full coupler length. It is used for applications where it is difficult but not impossible to rotate the continuation bar.

Bartec Type C:-The Bartec Type C system has an additional locknut and is used where the continuation bar cannot be rotated. The continuation bar is threaded for the full coupler length plus the length of the locknut.

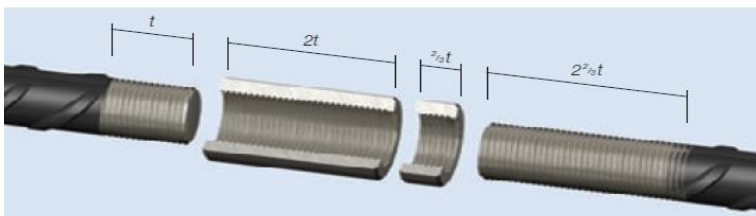


Figure 2.11: Bartec couplers Type C [20]

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

2.4.6.1.9. Bar X-L couplers

Each bar to be joined is cut square and marginally enlarged by a cold forging process in order to increase the cross-sectional area of the bar. This ensures that the joint is stronger than the bar. The Bar X-L system differs from the Bartec system because the thread applied to the bar is rolled onto the enlarged ends of the bar rather than cut into it. As with the Bartec system the threaded end is then proof tested to a force equal to the characteristic yield strength of the bar. This method of thread formation provides Bar X-L couplers with enhanced fatigue resistance. Where fatigue is a major consideration on a project, the external surface of the coupler can be profiled. Plastic end sheaths protect the threaded ends of the rebar. The internal threads of the couplers, which are usually supplied fixed to the bar, are protected by internal plastic end caps [20].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Table 2.7: Bar X-L Dimensions [20]

Bar diameter	12	14	16	18	20	22	24	25	26	28	32	36	40	50
External Dia.	19	22	25	28	31	34	36	40	40	43	49	55	60	75
Coupler Length	28	32	36	40	44	48	52	56	58	62	70	78	86	106
Thread Size	M14	M16	M18	M20	M22	M24	M26	M28	M29	M31	M35	M39	M43	M53
Thread Pitch	2.0	2.0	2.5	2.5	2.5	2.5	2.5	3.0	3.0	3.0	3.5	3.5	4.0	4.0
Weight (kg)	0.03	0.05	0.08	0.11	0.14	0.19	0.20	0.29	0.32	0.39	0.58	0.81	1.09	2.08
Part No Type A	XL1 2/A	XL1 4/A	XL1 6/A	XL1 8/A	XL2 0/A	XL 22/ A	XL 24/ A	X L2 5/ A	XL 26/ A	X L2 8/ A	X L3 2/ A	XL 36/ A	XL 40/ A	X L5 0/ A
Part No Type B	XL1 2/B	XL1 4/B	XL1 6/B	XL1 8/B	XL2 0/B	XL 22/ B	XL 24/ B	X L2 5/ B	XL 26/ B	X L2 8/ B	X L3 2/ B	XL 36/ B	XL 40/ B	X L5 0/ B
Part No Type C	XL1 2/C	XL1 4/C	XL1 6/C	XL1 8/C	XL2 0/C	XL 22/ C	XL 24/ C	X L2 5/ C	XL 26/ C	X L2 8/ C	X L3 2/ C	XL 36/ C	XL 40/ C	X L5 0C

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Bar X-L Type A:-The Bar X-L Type A system utilizes internally threaded couplers with a single right-hand thread and is suitable for applications where the continuation bar can be rotated. The ends of the bar are upset and threaded for half the length of the coupler.

Bar X-L Type B:-The Bar X-L Type B uses the same coupler as the Type A system, but one bar is threaded for a full coupler length. This is for applications where it is difficult but not impossible to rotate the continuation bar.

Bar X-L Type C:-Where fatigue is a major consideration, the Bar X-L Type C system has additional locknuts and is used where the connecting bar cannot be rotated. The continuation bar is threaded for the full coupler length plus the length of the locknut [25].

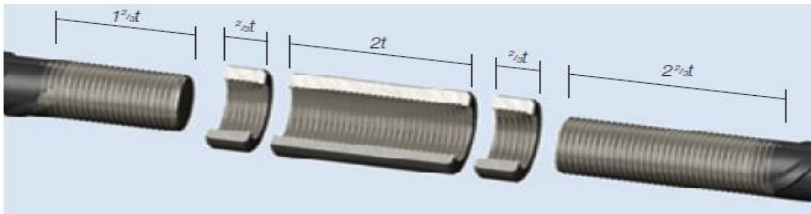


Figure 2.12 : Bar X-L couplers Type C [25]

2.4.6.2. Non-threaded couplers

Non-threaded Couplers: - This type of couplers have variety of types which are used in areas where the threaded couplers cannot be employed. This type of splice can resist stress, it should be known that the end of the re-bars needs to be saw cut, but no special end preparation is needed for reinforcement bar [25].

2.4.6.2. 1. Tension Only Splices

This type of splice is suitable for the case where tension forces are present only. Therefore, if such condition is not guaranteed, then it is recommended to avoid its use. Shear screw and double wedge coupling sleeve and steel coupling sleeve with wedge are two examples of mechanical lap splices [19].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

2.4.6.2. 2. MBT mechanical coupler splice

The MBT range of couplers provides a cost-effective method of joining reinforcing bars, particularly when the fixed bar is already in place and there is insufficient space for a hydraulic swaging press. The bar ends are supported within the coupler by two serrated saddles, and as the lock shear bolts are tightened, the conical ends embed themselves into the bar.

As this happens the serrated saddles bite into both the bar and the shell of the coupler. In all cases heavy duty sockets should be used. When the pre-determined tightening torque for the bolts is reached, the heads shear off leaving the top of the installed bolt slightly proud of the coupler [20].

MBT ET series coupler splice : -The MBT ET series of couplers is used to connect reinforcing bars of the same size. Section showing the embedment of the lock shears bolts and saddles into the bar and the shell of the coupler.

Table 2.8: MBT ET Series Dimensions [20]

Bar diameter	10	12	14	16	20	25	28	32	34	40
External Diameter	33.4	33.4	42.2	42.2	48.3	54.0	66.7	71.0	75.0	81.0
Total Length	100	140	160	160	204	258	312	312	420	484
Socket Size A/F (ins)	1/2	1/2	1/2	1/2	1/2	5/8	5/8	5/8	3/4	3/4
No. of Bolts	4	6	6	6	8	8	10	10	12	14
Approx Weight (kg)	0.52	0.72	1.25	1.25	1.96	3.00	5.80	6.50	8.72.	11.30
Part No	ET10	ET12	ET14	ET16	ET20	ET25	ET28	ET32	ET34	ET40

MBT transition series coupler splice : -The MBT Transition series of couplers provides an effective solution for connecting bars of different diameters. They can be installed without any preparation to the bar ends and without any need to rotate bars. The coupler can be rotated to allow access to the bolts for tightening with either a ratchet wrench or a nut runner. In all cases heavy duty sockets should be used, Transition couplers are non-standard and are made to order [20].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Table 2.9: MBT Transition Series Dimensions [20]

Bar diameter	16/12	20/12	20/16	25/16	25/20	32/20	32/25	40/32
External Diameter (mm) d	42.2	48.3	48.3	54.0	54.0	71.0	71.0	81.0
External Diameter (mm) d2	26.4	33.4	48.3	42.2	54.0	48.3	54.0	71.0
Total Length (mm) l	160	150	160	155	180	177	231	335
Individual Lengths (mm) a:b	80:80	80:70	80:80	75:80	90:90	75:102	102:29	178:157
Socket Size A/F (ins) a:b	1/2:1/2	1/2:1/2	1/2:1/2	5/8:1/2	5/8:1/2	5/8:1/2	5/8:5/8	3/4:5/8
No. of Bolts a:b	3:3	3:3	3:3	2:3	3:3	2:4	3:4	5:5
Torque (Nm)	108:55	108:55	108:108	275:108	275:108	360:108	360:275	525:360
Part No.	ET16/12	ET20/12	ET20/16	ET25/16	ET25/20	ET32/20	ET32/25	ET40/32

MBT continuity series coupler splice : -The MBT Continuity coupler allows reinforcement to be extended at construction joints without the need to drill or otherwise substantially deface the formwork. The female part of the coupler is fixed to the formwork with the aid of a nail plate. After removal of the formwork, the nail plate protects the internally threaded end of the coupler. It is advisable to loosen the nail plate to break the bond with the concrete whilst it is still 'green'. When the nail plate is removed, the male section can be screwed into the existing section of the coupler [25].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

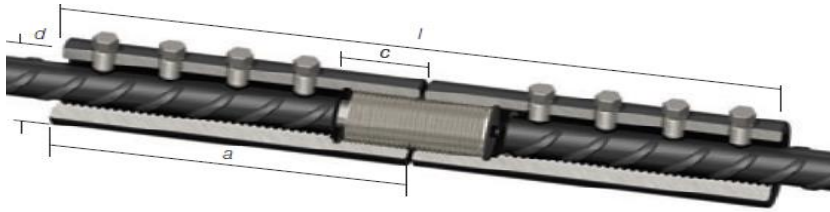


Figure 2.13: MBT Continuity Series [25]

Table 2.10: MBT continuity series coupler Dimensions [25]

Bar diameter	12	16	20	25	32	40
External Diameter (mm) d	33.4	42.2	48.3	54.0	71.0	81.0
Maximum Length (mm) l	250	280	349	414	490	675
Female component Length (mm) a	100	115	147	177	214	300
Threaded Section (mm) c	30	35	38	43	53	53
Socket Size A/F (ins)	1/2	1/2	1/2	5/8	5/8	3/4
No. of Bolts	6	6	8	8	10	14
Nail Plate Diameter x Thickness (mm)	75 x 5	75 x 5	75 x 5	100 x 5	100 x 5	127 x 5
Approx Weight (kg)	1.40	2.20	3.70	5.15	11.5	18.8
Torque (Nm)	55	108	108	275	360	525
Part No.	C12	C16	C20	C25	C32	C40

MBT headed anchors :-MBT Headed Anchors are designed to provide dead end embedment for bars in concrete. This helps to reduce congestion and simplify the placement of rebars by removing the need for hooked ends. The anchor comprises half an MBT coupler with a plate welded to one end which carries the full tension load of the bar when it is bearing against the concrete. The MBT Headed Anchor also has the added advantage of requiring no special bar end preparation [25].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Table 2.11: MBT headed anchors Series Dimensions [25]

Bar Diameter	12	16	20	25	32	40
External Diameter (mm) d	33.4	42.2	48.3	54.0	71.0	81.0
Coupler Length (mm) l	75	82	104	129	156	247
Total Length (mm) lo	85	92	114	139	171	262
Plate Thickness (mm) t	10	10	10	10	15	15
Plate w x h (mm) p	70	80	90	100	130	150
Socket Size A/F (ins)	1/2	1/2	1/2	5/8	5/8	3/4
No of Bolts	3	3	4	4	5	7
Approx Weight (kg)	0.74	1.07	1.58	2.29	4.72	8.30
Torque (Nm)	55	108	108	275	360	525
Part No.	ETHA12	ETHA16	ETHA20	ETHA25	ETHA32	ETHA40

2.4.7. Mechanical coupler installation procedure

The coupler system is designed to connect two pieces of rebar together in the field quickly and easily. The couplers are installed using the following steps, The coupler is normally supplied to a reinforcing bar, ready to be installed and cast in concrete, after casting of the concrete and when ready to extend, remove the plastic end cap from the coupler.

Position the continuation bar in the sleeve and rotate the bar into the coupler and continue to screw the bar into the coupler until tight and to ensure correct installation, tighten the joint to the specified torque using a calibrated torque wrench on the continuation bar [22].

2.4.7.1. BARTEC coupler splice installation procedure

The Bartec Type A System:-Screw the coupler to the rear of the thread on the fixed bar, lock tight and the bar end should be central within the coupler[15].



Figure 2.14: The Bartec type A system coupler installation phase-1[15]

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Remove the plastic cap from the coupler, Position and rotate the continuation bar in the coupler [15].



Figure 2.15: The Bartec type A system coupler installation phase-2[15]

Tighten the joint using a wrench on the continuation bar, after tightening there should be no more than 2-4mm of thread exposed, depending on the diameter of the rebar [15].



Figure 2.16: The Bartec type A system coupler installation phase-3[15]

2.4.8. Coupler selection for a construction structurale system

There are many situations that require the use of mechanical splices over the use of conventional lap splices. Mechanical splices are an attractive alternative for providing continuity and anchorage to “hoop” or continuous spiral reinforcement used to provide confinement in columns. Other applications include relieving congestion and reducing the reinforcement ratio in splice regions and in splicing new reinforcing steel to existing steel in patches, closure pours and structural additions [8].

Current codes do not allow diameter of 43mm or 57mm bars to be spliced using a lap splice requiring mechanical splices for these bar sizes. Other uses of mechanical splices are in portions of a structure affected by seismic loads as recommended by new revisions [8].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

The choice of the mechanical coupler system for the project depends on various factors. Selection of the most suited coupler system should be made after considering all advantages and limitations of the coupler system, the project parameters, location of coupler joint and the preferences of the structural consultant for the project. The main application of non-threaded couplers is in repair works than new construction works [15].

Mechanical reinforcing bar couplers, anchorage, structural products, precast connectors and similar value-added engineered splice systems offer a variety of solutions to meet the challenges of heavy construction [15].

This, together with the quantity to be fixed and the location, will determine which is the most appropriate coupler for a particular situation. The following table provides a guide when selecting the most appropriate couplers for specific applications [15].

Table 2.12: Selecting couplers the most appropriate tasks [15]

Application	BT	MBT
Wall to slab connection	✓	
Wall to pre-cast beam connection	✓	
Column construction	✓	✓
Extension / repairs to existing structures		✓
Pre-cast element to pre-cast element connection	✓	✓
Closing of access openings	✓	✓
Rebar cage pre-fabrication	✓	✓
Hook bars to pile connection		✓
Fatigue applications	✓	✓
Bar end terminations	✓	✓

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

2.4.9. Cost comparison splice type of reinforcement bar

The reinforcement couplers splice not only provide tensile and compression strength to the splice but they are also an economic means of splice two bars. Mechanical coupler splice is cost effective and they are usually made with proprietary splice devices of which the effectiveness and application is accomplished on a per piece basis, providing that they satisfy the code requirements [39].

The total cost of welded splice is the cost of weld in addition to the cost of steel for lap length, lap length is equal to double the effective weld length. A cost has been computed based on saving of steel in lapping which indicates couplers are an effective and an economic replacement of lap and weld splice does not include installation and position cost.

How couplers have effectively saved a huge amount of money in a single splice. The total cost saved per joint for 25 mm rebar is Rs. 225/- and for 32 mm rebar is Rs. 499/- which is very less than what would have been spent if lapping would have been done by using site method. On the same line for 12 mm and 16mm rebar the saving is comparatively less [39].

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

CHAPTER THREE: EXPERIMENTAL PROGRAM

3.1. Introduction

This chapter reports the experimental program of the research that conducted ways of splice the reinforcement bars i.e. lap splice, lap welded splice and mechanical coupler splice. For comparison purpose an incremental tensile load tests and flexural test were carried out on lap welded splices, lapping splice and coupler splices. The results were analyzed and the feasibility of the specimens was determined based on several evaluation criteria. The experimental work will be described in the following sections:

Section 3.2 Provides a description of the facilities and material for laboratory testing of the beam specimens and tensile test of splice using coupler, lapping and lap welding of reinforcement. Section 3.3 Describes the experimental study that was done on preparation of test specimen was used to concrete, beam specimens and tensile test of splice type.

Section 3.4 Description of testing procedure describes the experimental work on tensile and flexural member, where a tensile test was made to find the material properties of the coupler and welding used in reinforcement splice for structural element construction.

Details of the specimens, test set-up and the properties of the materials used are presented in this chapter.

3.2. Facilities and materials for experimental testing

All materials provided by local suppliers were procured from a single batch for each lab test material. Materials were stored in the laboratory for at least one week prior to the beginning of lab test. The preparation of the required materials, as well as the testing of the specimens were carried out in the Civil Material Laboratory at the AAIT and Mechanical Laboratory at the Debre Birhan University for welding and coupler preparation.

The mechanical coupler used in this experimental work were internal threaded coupler from mild steel diameter of 20mm, 25mm and 30mm diameter for Fe500 external threaded reinforcement steel bars of diameters, 14mm, 16mm and 20mm were used for study.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Couplers are manufactured on a metal lathe machine. It rotates the work piece on its axis to perform various operations such as cutting, sanding, knurling, drilling, or deformation with tools that are applied to the work piece to create an object which has symmetry about an axis of rotation.

Table 3.1: Production of Coupler and Reinforcement thread (Debre-Birhan University)

Reinforcement diameter(mm)	Drill diameter(mm)	Internal and external thread diameter(mm)	Coupler external diameter (mm)	Pitch (mm)	length(mm)
14	12	M2x14	20	2	70
16	14	M2x16	25	2	80
20	18	m2x20	30	2	100

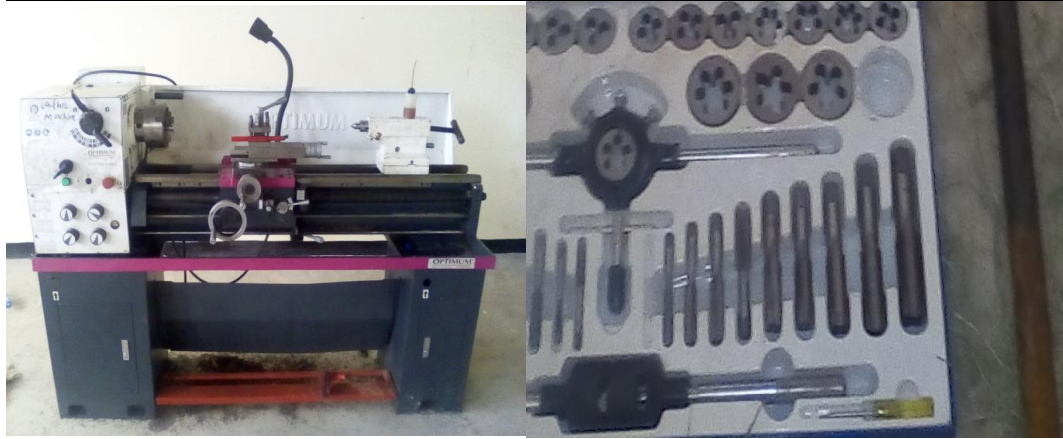


Figure 3.1: Lath Machine with Internal and external threader (Photo Mechanical Lap from Debre Brhan University)

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction



Figure 3.2: Coupler internal and external reinforcement thread (Manufacturing external and internal thread from Debre Birhan University Mechanical Lab)

For beam flexural test yield strength of bottom longitudinal reinforcement and upper longitudinal reinforcement used in the bottom bar splice region were 500MPa for diameter 16 mm and 12 mm, respectively. The bottom longitudinal steel reinforcement was 2Ø16 tension bar lapping using coupler, lap welding and overlapping splice of reinforcement.

Three beams are control beam with continuous reinforcement and the other nine beams for each splice three type beam with splice of tension reinforcement by lapping, lap welding and coupler splice bar for beam specimen is lapped with addition of 75mm of hooked end tension reinforcement bar. The concrete compressive strength 25MPa with local quarry coarse aggregate of size 20mm and size of manufactured sand is less than 4.75mm, used as fine aggregate in addition to ordinate Portland cement (OPC).

Table 3.2: Proportions of ingredient of Concrete

Ingredient	Content(kg/m ³)
Water (net mixing)	188
Cement	311
Fine aggregate	839
Coarse aggregate	1006

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Twelve concrete cube sample were taken from mixer to measure three days, seven days and twenty-eight days concrete compressive strength. The concrete grade is **C-25** and its three days, seven days and twenty-eight days average compressive strength test result is **23.2(Mpa)**, **26.3(Mpa)** and **34.6(Mpa)** respectively. There for the twenty-eight days compressive strength attain the required strength value which is above **25(Mpa)**.

3.3. Preparation of experimental specimen

All of the steel bars used for experimentation are from the same manufacturing company. Before actual start of beam work all reinforcement, specimens were tested in laboratory in order to check their stipulated property. Tensile test conducted for mechanical spliced rebar and lap welded rebar used for the tensile test in order to check the performance of the splices according to the normal rebar for each diameter. These tests are carried out whenever reinforcement bars from a new supplier and splice type make in mechanical laboratory are to be used skeletons of any structure all tests on their purpose have to be carried out.



Figure 3.3: Reinforcement Bar Tensile Test Machine (From Adiss Ababa University Institute of Technology Civil Lab)

Before casting of beams work the slump, test is carried out using a 20 cm by 30 cm top and bottom cross-sectioned conical section.

This is carried out to check workability of the concrete so, concrete is placed in this conical section and the cone is removed, then the height difference between the cone and the concrete is measured and workability is checked.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction



Figure 3.4: Slump test (From Adiss Ababa University Institute of Technology Civil Lab)

For compressive cube test the sample collected in 15cm by 15cm by 15cm cubical section which is oiled prior to filling the oil helps in the smooth removal of the cubes later. Typically, 150 x 150 x 150mm cubes were cast with each test beam and used for compression test.

A few hours after casting, the beams and the cubes were covered with wet cotton sheets. Beam formwork stripping was done after a day from casting, the beams and the cubes were kept under the same curing conditions.



Figure 3.5: Beam Casting Sample (From Adiss Ababa University Institute of Technology Civil Lab)

The compressive strength testing machine applies load gradually, the machine has a pressure gauge indicating load by which the sample has failed and another indicating that the cube of concrete has stopped resisting load and application of load should be stopped.

Concrete tests are carried out for a 3 days, 7 days and 28 days strength result. The point at which the concrete fails load is recorded and is divided by area in mm².

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction



Figure 3.6: Concrete Compression Cubes Test Machine (From Adiss Ababa University Institute of Technology Civil Lab)

The twelve reinforced concrete beams concrete mix used for all the specimens was designed to achieve 25 N/mm² compressive strength at 28 days, were tested in positive bending.

The loading system was designed to produce a constant moment in the middle of the beam specimen under point loading arrangement. The loading was positioned in length of 530mm from support, with the ratio of shear span to effective depth (a_v/d) is 2.65.

The dimension of both beams is 200mm width, 200mm height and 1200mm long and concrete cover was constant in all sides of beams and equal to 25mm. The reinforcement bar used in this experiment was tensile strength steel with grade of 500 N/mm² for reinforcement bar. In details, the bar size for stirrups, compression and tension reinforcement used 8mm, 12mm and 16mm respectively. Reinforcement on the tension side consisted of two 16mm diameter deformed bars spliced by using splice type at mid-span of the beam and 8mm diameter deformed bars stirrup placed at spacing of 100mm entire length of the beam.

3.4. Description of experimental procedure

Three samples for each diameter of \varnothing 14, \varnothing 16, \varnothing 20 are used for the tensile test in order to check the performance of the splicers for each diameter. The rebar is 80-centimeter length, the center, left and right of the 80-centimeter bar is then marked.

Apply an axial tensile load to the sample sufficient to cause failure with the maximum load obtained and calculate the ultimate tensile strength by dividing the maximum load by the sample's nominal cross-sectional area then record the yield and ultimate tensile strength on the test form.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Yield strength being the point where resistance to load sharply stops then the final point where the bar breaks is the point call the ultimate tensile strength. A tensile test machine able to apply a tensile force greater than the ultimate tensile strength of the sample. Tensile testing is required for all normal, mechanical and lap welded splices must be performed in accordance with ASTM A 370 as document the ultimate load obtained and the location of the bar affected zone as figure 3.3, above.

The experimental set up for beams is given in fig.3.8 below where LVDT are connected in the mid span of the beam. The specimens were simply supported by steel with effective length of 2000mm and subjected to point loading located above the beam the load point load symmetrically. Lines locating the positions of point loads, supports and the middle of each beam were marked. Beams were placed in the testing frame that uses hydraulic jacks. The effective length of each beam was kept at 1060mm measured from the center of each support. All the beams were designed to ensure that the beams will only fail in flexure failure rather than lap splice beam lead shear failure. Support is given by leaving 70mm from both edge of the beam and point loading is provided at a distance of 530m from the support. For the preparation of testing, the surface of the specimens was painted using white emulsion paint to aid the process in detecting the cracking development during the test at 28 days, when the concrete mixture reached the required strength as designed, the beams were prepared for testing.

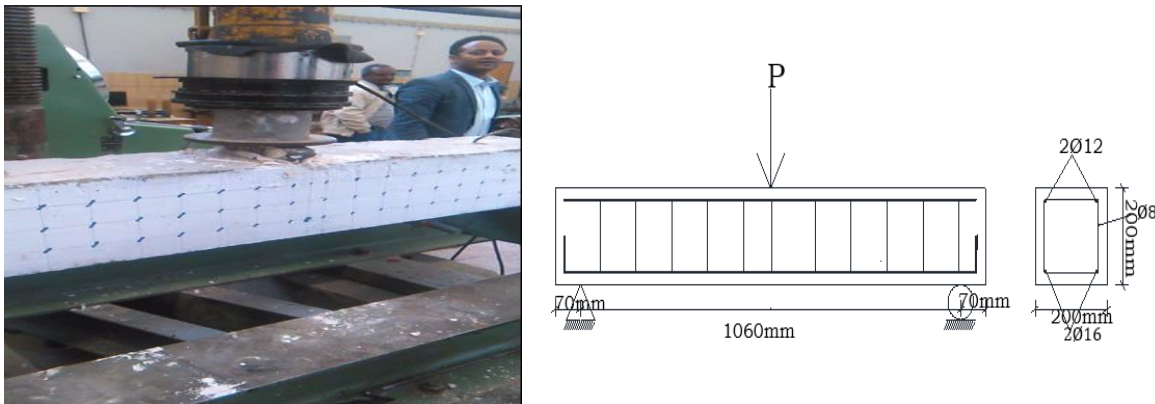


Figure 3.7: Beam set up for flexural test (From Adiss Ababa University Institute of Technology Civil Lab)

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

The load was applied through a Mechanical screw jack and transferred to the test beam through steel rollers of the beam. The main testing apparatus used were Magnus Frame, Data Logger and Hydraulic jack. Load was applied using a 1000kN capacity Hydraulic jack in compression. The jack was equipped with a calibrated 200kN Load Cell to measure the load during the increment process. The load was measured using an Electrical Load Cell under the Screw Jack with a maximum capacity of 200KN.

The deflections were measured by Linear Variable Displacement Transducers (LVDTs), placed under the middle of the beam span. The Load Cell and LVDTs were connected to a data acquisition system to record the data. The load is applied at each step and continued until failure. The load was applied to the specimens until cracking was observed on the tension side of the beams and the cracks were traced. Cracks at the faces of the specimens were marked for further analysis.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1. Comparison splice type of reinforcement bar

Reinforcement lapping and lap welding is doubling the steel to concrete ratio at lapping zone resulting reinforcement congestion which limit the flow and distribution of larger aggregate particles and the effectiveness of vibration. Because the addition of reinforcement bar for splicing will increase the area of reinforcement with in the section to minimizing spacing of the reinforcement beyond the minimum spacing required. For lap welding and lapping reinforcement bar wastage due to end pieces used for lapping and those being thrown away when no longer needed which lead additional cost of material in construction.

To solve this problem standard mechanical coupler splices should be applied since it reduces this reinforcement congestion due to in line splice and cost of material.

4.1.1. Reinforcement bar lapping splice

The strength of lapping depends on the concrete for continuity, lapping is only permitted in lapping zones by lapping length and dowel bars are required, subject to high steel congestion, finally lapping procedure in construction is tedious and high labor cost for installation and handling of steel, no strength verify by third parties and no continues path of strength. Rebar metallurgically unchanged, applicable for all rebar size and type with all rebar finish.



Figure 4.1: Reinforcement Steel Congestion Lap Splices (photo from Building Construction around Pissa in front of Adiss Abeba Municipality)

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

4.1.2. Lap weld reinforcement splice

Reinforcement lap welds provide rigid splice that do not work separate during handling of the weld reinforcement or placing of the concrete. Welding of reinforcement bars is a practical means of developing the force transfer required in reinforcement bar weld splice, Strength independent of concrete and no strength verify by third parties, continues path of strength, requires excess reinforcement, no reduces congestion, rebar metallurgically changed, no applicable for all rebar size, type and finish. In Ethiopia not commonly used in construction industry.



Figure 4.2: Lap Welding Splice Reinforcement steel (Photo Lab Tensile Test Reinforcement)

4.1.3. Mechanical coupler reinforcement splice

Mechanical coupler splicer, there is no need of additional lap length since the mechanical coupler splices is the main force transfer mechanism. Acts as a continuous bar on its own because it has a mechanical joint threaded coupler design provides continuity and structural integrity. In my tensile test develops equivalent tensile strength with continuous reinforcement, lapping length is not required to worry about giving the wrong lapping length or the reduction of concrete grade. Mechanical coupler reinforcement splice can be used and outside lapping zones so, steel congestion is not an issue, Overall quality of the structure increases because the concrete is allowed to flow freely especially in critical sections.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

More structural integrity than lap splices because reduces the amount of rebar, which reduces the labor and crane time improving the construction schedule with no lapping length which lowers material cost. Strength independent of concrete and verify by third parties, continues path of strength, requires no excess reinforcement lead to reduces congestion, rebar metallurgically unchanged, no applicable for all rebar size, applicable for all rebar type and finish. Mechanical splice has none of the limitations of welded splices or lap splices and tested performance independent of the concrete applicable for every construction site.



Figure 4.3: Mechanical Splice Reinforcement Steel (photo Adey Abeba Stadium from Geriji Emprial)

4.2. Mechanical coupler splice procedure

Standard Coupler splice two bars of the same size where at least one bar is free to rotate coupler made from the rebar and splice two bars of same size during staged construction. Couplers especially threaded one can simplify the design and construction of reinforced concrete structure and reduce the amount of reinforcement required. The bars are threaded at the ends and splice to a coupling with matching internal threads to complete the splice of reinforcement bar or these bars must have threaded rebar ends to fit into the coupling and then the splice is tightened onto the rebar.

The couplers are normally supplied fitted to the end of threaded bar, requiring only the engagement and tightening of the adjoining bar on construction site, Coupler will be hand tightened onto threaded bar and fixed directly on the rebar splice the bars.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Both mechanical couplers and threaded bars are supplied in to the construction project, Couplers are used to create threaded splice between reinforcement bars proper tightening of the system in accordance with the installation instructions. Tolerances are provided using oversized coupler in the splice threading reinforcement bar.

At least one bar can be moved axially and rotated with full tension and compression capacity. Visual inspection of the finished splices is sufficient for full insert threaded reinforcement bar with half-length both side of coupler splice. Threaded coupling strength characteristics mainly depend on in situ threading reinforcement bar quality.

4.3. Application of mechanical coupler splice in Ethiopia

Application mechanical coupler splicing method of reinforcing steel must frequently be continued across construction reinforcement splice this means that rebars, the main reinforcement used to provide mechanical coupler splice in the main reinforcement, beyond the first placement of concrete structure. Standard threaded coupler is used mechanical splicing system in Ethiopia specifically Addis Abeba at Commercial Bank of Ethiopian Head Office around Stadium and Adey Abeba Stadium around Imperial Gerji uses mechanical splice for shear wall reinforcement splice, footing reinforcement splice, column reinforcement splice and beam reinforcement splice for new construction, staggering splices uses at lap region, which can result in adequate concrete flow into the splice area and prevent weak joint in splice region.



Figure 4.4: Mechanical Splice Reinforcement steel (photo from Commercial Bank of Ethiopia Head Office Building Construction)

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

4.4. Cost comparison splice type of reinforcement bar

The objective is mainly concerned economic comparison for the three method of splicing technique which are mechanical coupler, lap and lap welding splicing that are cost estimation and clear comparison is conducted for the three type of reinforcement splice.

The total cost of a structure depends primarily on the amount and cost of material used, the amount and cost of labor required to construct the facility, and the cost of equipment needed during construction. Lap splicing cost consists only the steel cost for lap splices. Labor costs for installing lap splices are not counted. Costs are always an influential factor in the choice of most concrete structures. The cost criterion cannot be separated from the criteria of efficiency in construction. Estimating the costs of a welding job can be a difficult task because of the many variables involved and the various projects that require this skill. The type of material used also has a major impact on the final cost of welding in the construction industry. Here the economic comparison was done for only material cost other additional labor and equipment costs is not included in this research.

Welding cost includes the lapped rebar cost and electrode cost over a length of $5\emptyset$, Mechanical coupler splice cost per piece basis based over a length of $5\emptyset$, Lapped rebar is cost of lapped reinforcement bar over a length of $40\emptyset$. This is the stage where the total cost of reinforcement bar by multiplying the quantity with the unit price.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Table 4.1: Bar splice cost comparison (Nine Splice type beam cast in Civil Lab)

Description		unit	Quantity	Rate(birr)	Amount(birr)
Mild reinforcement bar for flexure splice test					
A.Lap bar splice	Dim 16 deformed bar	Kg	18.38	56	<u>1029.26</u>
B.Weld bar splice	Dim 16 deformed bar	Kg	13.07	56	732.15
	Dim 3.2 electrode	Pcs	14	2.6	36
	Total				<u>768.15</u>
B.Coupler bar splice	Dim 16 deformed bar	Kg	12.32	56	689.7
	Dim 20 mild steel bar coupler	Pcs	6	12	72
	Total				<u>761.7</u>

The above table shows that the cost difference between mechanical coupler splices, welding splice and overlapping reinforcement bar. When the diameter of 16mm of reinforcement bar used in flexural test the mechanical splices cost difference 9.5%, overlapping splices cost difference is 32.99% and welding splices is 10.21% as compared to control beam, so mechanical coupler splice is cost effective than lap and weld splice in this research.

4.5. Spliced reinforcement bar tensile strength test result

Result obtained from the tensile test result evaluated and compared to the tensile strength and failure mode of each specimen for respect to the type of reinforcement bar splice. Tension tests were performed on short bar sections to determine actual yield strengths. The forces causing tension for reinforcement tensile test, when a stretching force (tensile force) is applied to reinforcement bar, it will extend with tensile load of complete yield failure of the cross section of the bars.

Experimental test conducted for mechanical spliced rebar or lap weld splices in different rebar splices in three trials diameter reinforcement bar that undertake in the research are 14mm, 16mm and 20mm in order to check the performance of the weld and coupler splicer for each diameter with enough embedment.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

The mechanical couplers and weld splice are located at the center of the test specimen is applied on the lapped region. The specimens are fit to the test machine and axial tensile load is applied to the sample in tension sufficient to cause fracture.

When increase the diameter of reinforcement bar diameter and length of mechanical coupler splice increase. The tensile test result of coupler and lap welding splice shows that each tensile strength equivalent the nominal yield strength of continuous or normal reinforcement bar calculated for spliced reinforcement bar primarily rupture near on the mechanical spliced and lap weld spliced that is heat affected zone. Lap weld and coupler reinforcement splice failure is brittle failure type because there is no enough reinforcement specimen deformation these tests the failure of the reinforcement bar for loads up to the yield point rupture region of the reinforcing steel.

In mechanical coupler reinforcement splice tensile test three type of failure under tensile test that are coupler rupture, reinforcement rupture and slipping of reinforcement from coupler.

The area of welded splice stress has already more than the yield stress of normal reinforcement bar because the lap weld test rupture at the end of lap weld and at heat affected zone.



Figure 4.5: Welding and Coupler splice after tensile test

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Table 4.2: Average comparative results of tensile test for normal and spliced rebar

Samples: I, II and III	Normal Bars (I, II & III)			Coupled Bars (I, II & III)			Welded Bars (I, II & III)		
	14-TS	16-TS	20-TS	14-TS	16-TS	20-TS	14-TS	16-TS	20-TS
a) Yield stress Obtained (N/mm ²)	558.44	586.52	597.35	554.83	574.9	484.4	558.95	579.55	469.42
a) Ultimate stress Obtained (N/mm ²)	726.63	691.68	695.44	554.84	574.9	484.4	558.95	579.55	469.42
Elongation (mm)	21.4	22.5	22.7	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
Failure point	-	-	-	Near coupler	Near coupler	Near coupler	Near welded	Near welded	Near welded

The performance of each connection in this test is checked by observing where the reinforcement fails under the tensile fractured zone is near to the welded and coupler region.

The ability of the coupler and welded splice member is not sustaining deformation beyond the elastic limit while maintaining a reasonable load carrying capacity until total failure.

4.6. Flexural behavior and crack pattern in beam under different type of splice bars

An experimental program has been conducted in order to investigate the flexural behavior of reinforced concrete beams by changing the tension reinforcement splice type according to control beam with normal reinforcement bar. After ensuring no shear failure and its failure type is flexural failure for failure load, it has casted twelve beams for static load test.

For each type of reinforcement splicer three beams casted for average result, totally twelve reinforced beams develop flexural failures, were tested in AAIT Civil Material Lab.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

The beams were tested on a span of 1200mm with the central load of 600mm having a constant bending moment. After twenty-eight days of casting the beam tested for bending and the test result of the load-deflection and the crack pattern is recorded.

In the investigation of the effect of concentrated loads on reinforced concrete beam it has been necessary to plan and interpret tests of reinforced concrete sections of various kinds reinforcement splice. The results from the flexural strength testing for all reinforced concrete beam splice type with respect to reinforced concrete control beam.

The reinforced concrete beams were reinforced on the compression and tension side with the tension two deformed bars spliced at mid span of the beams were tested in positive bending to improve or enhance the bond strength and ductility failure mode of the tension reinforcement splices, Transverse reinforcement was provided in the shear spans of all beams to avoid shear failure. The failure of Control beam under static load is flexure failure type and the ultimate failure load is almost equal to the assumed failure load.

4.6.1. Crack pattern for flexural beam

In this certain experiment the tensile strength (measured in flexure) is more important because it measures the ability of material to resist cracking, there was a clear increase in flexural bearing capacity.

The first flexural crack in all beams occurred randomly in the constant moment region on the tension side of the beam inside the splice length. Load was applied to the specimens until cracking was observed on the tension side of the control beams with cracks were traced, loading continued in this fashion until flexure failure using Screw jack.

The output data were recorded by the data acquisition system. The crack formation stage is ended and the stabilized cracking stage starts, no new cracks occur, but existing cracks widen. The steel reinforcement control beam failed in flexure by yielding of the steel bars.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

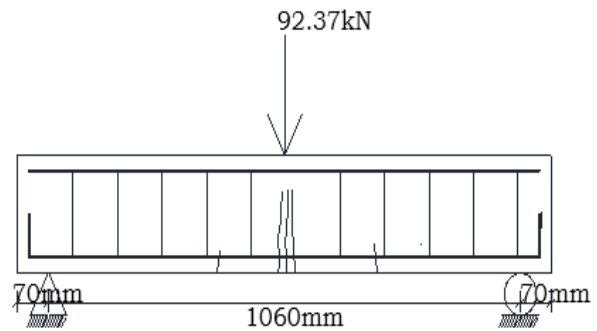


Figure 4.6: Crack pattern for control Beam

The failure of the beam with weld lap splice bars was governed by the formation of cracks along the splices before bar yielding, generally, the first cracks were vertical flexural cracks in the vicinity of the tension zone within welding lap end of reinforcement and near the constant moment.

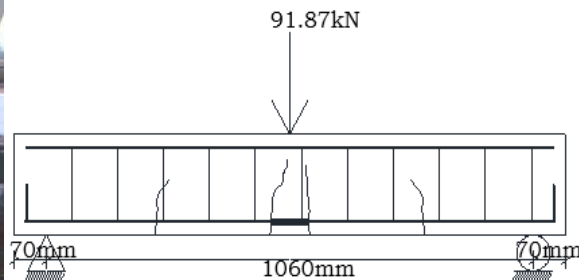


Figure 4.7: Crack pattern for welding Beam

As the load increased, cracks formed along the length of the constant moment region at the coupler splice end region in coupler beam. New cracks continued to form while existing ones propagated vertically toward the compression zone.

For the flexural failure, the flexural cracks extended upward to be very close to the top surface of the beam, very small longitudinal splitting reinforcement from coupler occurred along the splices, without a splitting failure.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

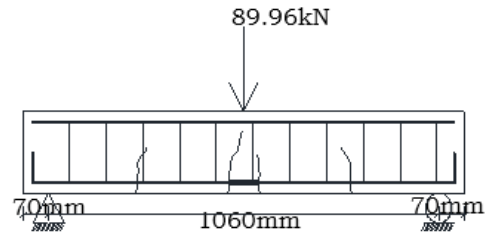
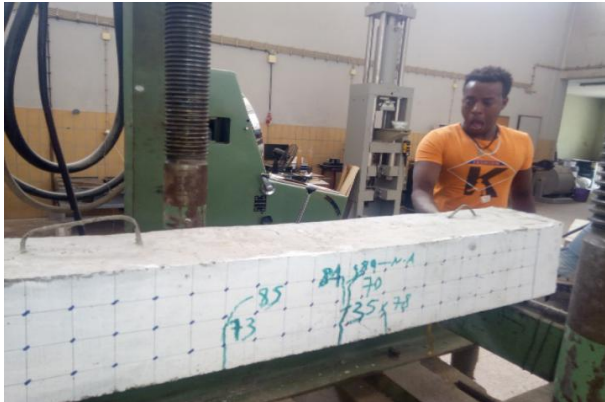


Figure 4.8: Crack pattern for coupler Beam

The typical cracks of lapping splice element are flexural shear cracks can be developing from flexural crack with shear cracks often will occur at the free end of the spliced bars.

The increase in spliced beam stiffness is a result of the extent of the reinforcement with double the tension cross-sectional area of bar with steel reinforcement ratio increase resulted in increased stiffness; this is due to the fact that the flexural stiffness is dependent on the internal tension steel reinforcement.

The strength and stiffness of the beams were substantially increased. The ultimate load carrying capacity of the beams increased by as much as 22.16% of control beam.

Two types of cracks can be seen. The vertical cracks occurred first, due to flexural stresses. These start at the bottom of the beam where the flexural stresses are the largest. The inclined cracks at the ends of the lapping splice beam are due to shear failure. These are commonly referred to as inclined cracks or diagonal tension cracks. Such cracks must exist before a beam can fail in shear.

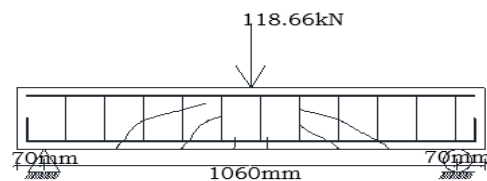


Figure 4.9: Crack pattern for lap Beam

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

As shown in the above figure the maximum crack appears at the mid span for control beam, welding beam and coupler beam rather than lapping splice beam maximum crack look at the end of reinforcement splice where the ultimate load is applied. At the initial stage the control and lap beams stiffness showed almost identical histories at low level of loading and up to the cracking load.

Table 4.3: Details of Ultimate Load and Load at First Crack

Specimen	Ultimate load (kN)	First crack load(kN)
Control Beam	92.37	44.18
Lap Beam	118.66	63.28
Weld Beam	91.87	46.85
Coupler Beam	89.96	41.43

The first crack load for all four-beam specimen is shown in table 4.2. The first cracking load is obtained for lap beam, Load is 63. 28kN. Then welding beam with first cracking load of 46.85 kN, coupler beam with first cracking load of 41.43kN and the control beam specimen has got first cracking load of 44.18kN.

Among all four beams, lap beam with reinforcement bar lapping has got greater first crack load that is 63. 28kN. It has got an increase of 30.18% first crack load as compared to the control beam specimen.

Weld beam with reinforcement lap welding has got greater first crack load that is 46.85kN. It has got an increase of 5.70% first crack load as compared to the control beam specimen. Mechanical coupler beam with reinforcement splice has got less first crack load that is 41.43kN. It has got decrease of 6.22% first crack load as compared to the control beam specimen.

Ultimate load of lap beam increase by 22.16%, weld beam decrease by 0.54% and coupler beam decrease by 2.6%.

4.6.2. Load- deflection curve for flexural beam

Load to deflection curve shows that the failure type of the beam either its ductile failure or brittle failure under flexural failure. Behavior of a flexural member is important for several reasons. Deflection is directly a function of the cross-section stiffness.

As the load increases the deflection in the beam also increases. It will enable the splices to reach higher bond strength before failure.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

After peak load, the bond strength decreased gradual propagation. Which beam fails load or the maximum load and deflection at that load is taken as maximum deflection at mid span reinforced concrete beam, after breaking point load goes on decreasing and deflection is increased. When the load attains maximum, the specimen got crushed due to the load applied by the Load Cell. The lapping splice beam specimens were carrying more load as compared to other beams and the deflection significantly increased, Load transfer mechanism of lap splice is dependent on the surrounding concrete causing significant forces to occur within the concrete.

The small different in deflection values for both beams may due to the stiffness of beam with the cause of splice type. Stiffness is a slope of load- deflection curve. In this case, with the applied load, reinforce concrete beam with one splice deflection compared with the reinforce concrete beam with another splice type. The Figure below shows load to displacement curve of the test beams.

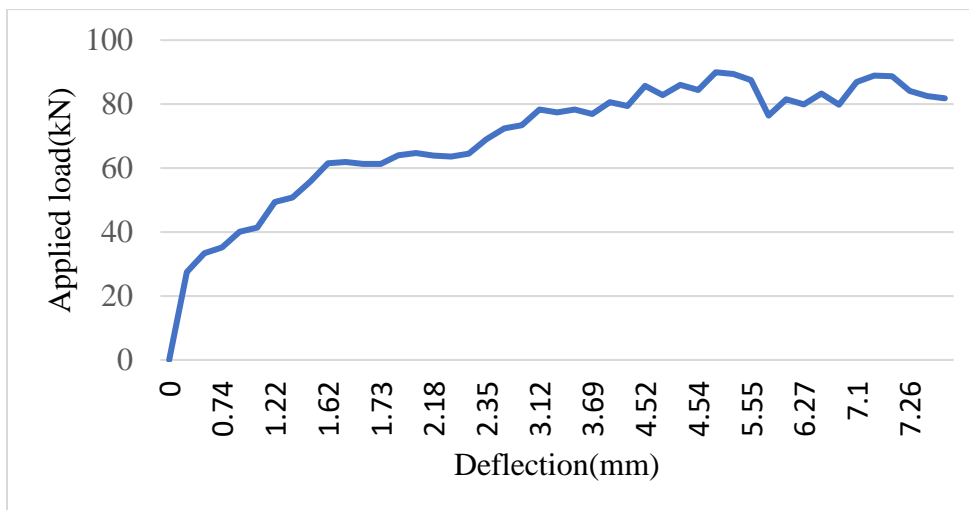


Figure 4.10: Load vs Deflection graph for coupler Beam

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

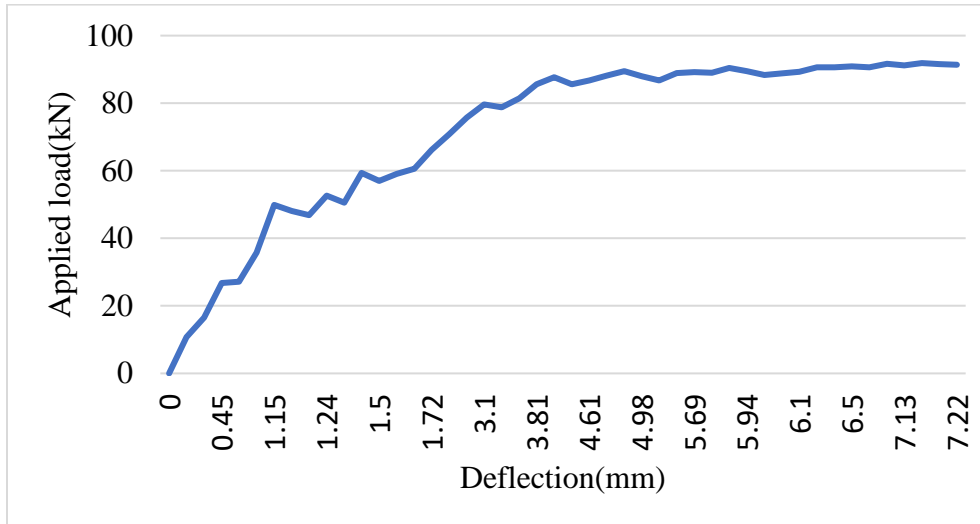


Figure 4.11: Load vs Deflection graph for weld Beam

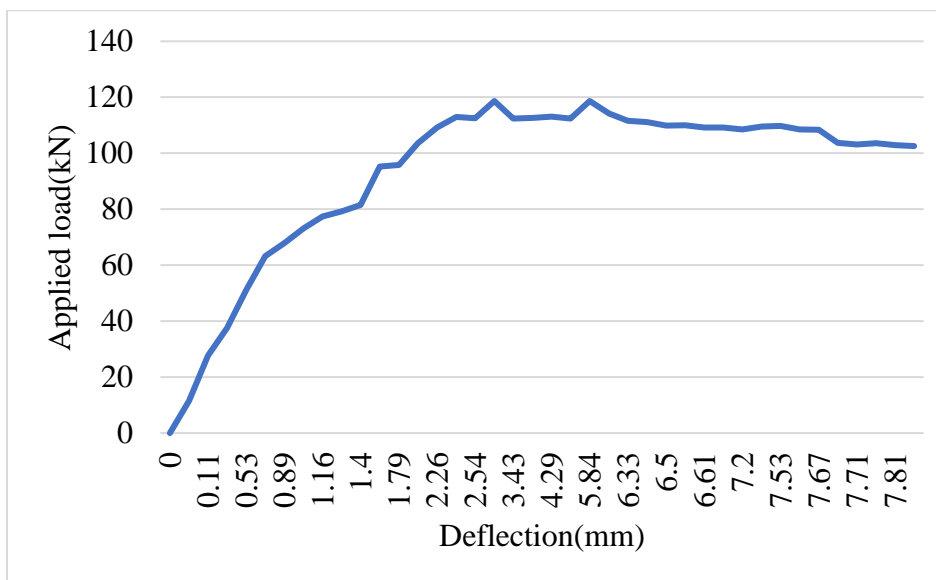


Figure 4.12: Load vs Deflection graph for lap Beam

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

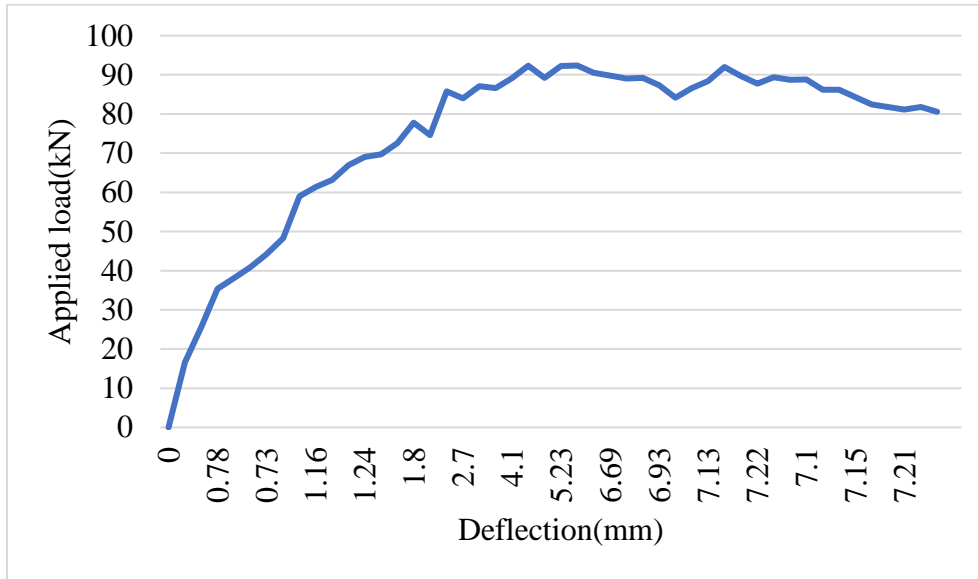


Figure 4.13: Load vs Deflection graph for control Beam

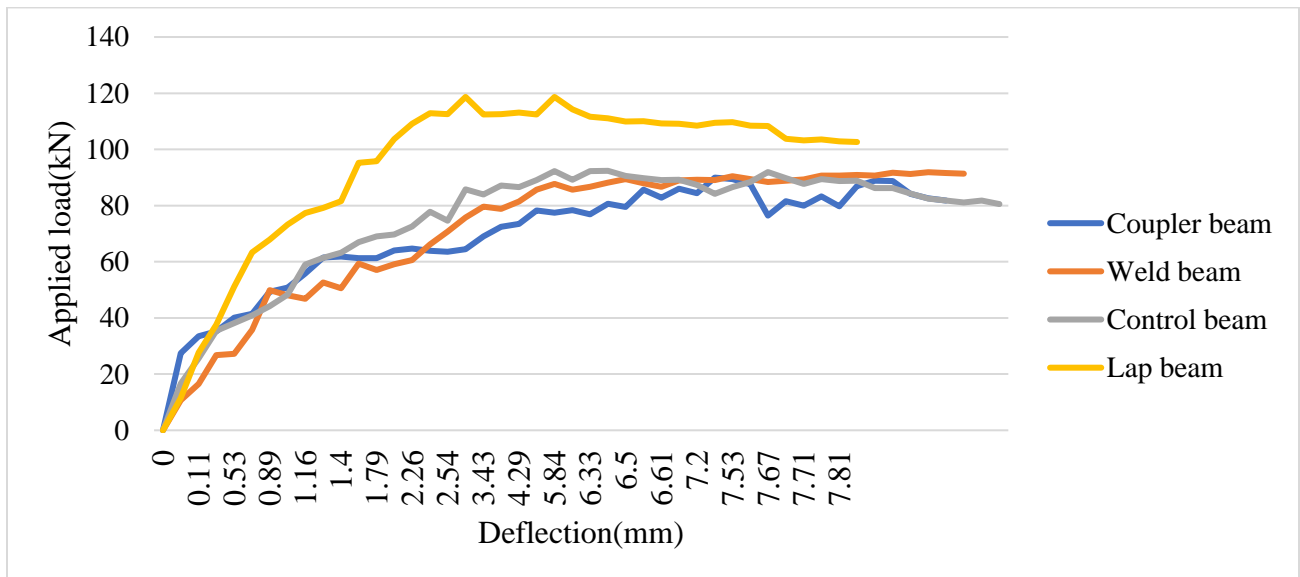


Figure 4.14: Load vs Deflection graph for all Beam

Among all four beams, lap beam with reinforcement bar lapping has got greater ultimate load compare to control beam that is 118.66kN. It has got an increase of 22.16% ultimate load as compared to the control beam specimen.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Weld beam with reinforcement lap welding has got less ultimate load as compare to control beam that is 91.87kN ultimate load. It has got decrease of 0.54% ultimate load as compared to the control beam specimen.

Mechanical coupler beam with reinforcement splice has got less ultimate load as compare to control beam that is 89.96kN ultimate load. It has got decrease of 2.6% ultimate load as compared to the control beam specimen.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This thesis examines the results of experiments on reinforcement splices type that is significant for many practical applications requiring a ductile situation where the reinforcement will yield before the splices fail, to prevent splice failures occur suddenly without warning and with dangerous results.

- Lap weld and coupler reinforcement splice tensile failure is brittle failure type because there is no enough reinforcement specimen deformation up to the yield point rupture near to the splice region of the reinforcing steel.
- Mechanical coupler splice beam and weld splice beam load-deflection have nearly the same as the control beam in flexural test.
- The lap beam with reinforcement bar lapping is found to have a better load carrying capacity and large deflection as compared to control beam due to the increase of reinforcement ratio.
- All the beams fail in flexure failure rather than lap splice beam lead shear failure and the crack starts at the end of reinforcement splice.
- The mechanical splices cost difference was 9.5%, welding splices was 10.21% and lap splice was 32.99 %, so mechanical coupler splice is cost effective than other splice in this research.
- The first crack load for lap beam increase by 30.18%, weld beam increase by 5.70% and mechanical coupler beam decrease by 6.22%.
- Ultimate load of lap beam increase by 22.16%, weld beam decrease by 0.54% and coupler beam decrease by 2.6%.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

5.2. Recommendations

- Lap weld splice heat affected zone problems and coupler splice brittle failures can be mitigated by performing a pre and post heat treatment.
- Construction stakeholders must be aware of mechanical coupler splice for current and future construction project to decrease construction cost by reducing reinforcement congestion.
- Researchers needed further investigation by increasing length, pitch of internal and external thread and increase the thickness of coupler.
- Researchers needed further investigation by increase the number and diameter of tension reinforcement splice type.
- Researchers needed further investigation for dynamic performance comparison.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

REFERENCE

- [1] American Concrete Institute (ACI), Building code requirements for reinforced concrete 3.5.2.
- [2] American Concrete Institute (ACI), Building code requirements for reinforced concrete 12.14.
- [3] American Concrete Institute (ACI), Building code requirements for reinforced concrete 12.15.
- [4] American Concrete Institute (ACI), Building code requirements for reinforced concrete 12.16.
- [5] American Concrete Institute (ACI), Building code requirements for reinforced concrete, 318M-95.
- [6] American Concrete Institute (ACI), Building code requirements for reinforced concrete, 318,2005.
- [7] American Concrete Institute (ACI), Building code requirements for reinforced concrete, 318,2008.
- [8] American Concrete Institute (ACI), Building code requirements for reinforced concrete,439.3R2005.
- [9] American Welding Society (AWS), Structural welding code reinforcing steel, D1.4-92.
- [10] *Arthur H.Nilson,David Darwin,Charles W.Dolan* ,Reinforced concrete thirteenth edition.
- [11] *Arthur H.Nilson,David Darwin,Charles W.Dolan* ,Design of concrete structure fourteenth edition, according to ACI 2008 .
- [12] ASME CC – 4330, 2004, Section III, Div 2.
- [13] British code of standard (BS), Building code requirement for reinforced concrete 8110-Part 1, Section 3, 1989.
- [14] British code of standard (BS), Building code requirement for reinforced concrete 5400: Part 4: 1990.
- [15] Dayton superior concrete construction product for rebar splicing handbook 2017.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

- [16] EBCS - 2, 1995, "Structural Use of Concrete", Ministry of works and Urban Development, Addis Ababa, 1995.
- [17] *Edward G. Nawy*, Reinforced concrete fundamental approach fifth edition.
- [18] *Gary, Connah*, Prequalification of mechanical splices for reinforcing bars in seismic conditions Australian Earthquake Engineering Society 2013 Conference.
- [19] *Harry B. Lancelot*, Mechanical splices of reinforcing bars.
- [20] <https://www.ancon.co.uk/downloads/advert/reinforcing%20bar.pdf>.
- [21] <https://www.bar-us.com>.
- [22] <https://www.halfen-moment.com>.
- [23] <https://www.keyence.com/ss/products/measure/welding>.
- [24] <https://www.marineinsight.com/marine-electrical/a-guide-to-welding-electrodes-on-ships-part-2>.
- [25] <https://www.masterbuilder.co.in>.
- [26] <https://www.theweldingmaster.com/types-of-welding-electrodes>.
- [27] <https://www.quora.com/What-is-the-chemical-composition-of-the-AWS-E6013-welding-electrode>.
- [28] Indian standard code SP:34 (S and T) – 1987 Section 4.
- [29] Indian standard code 456 cl.26..2.5 ,Reinforced concrete version 2 CE Kharagpure.
- [30] Indian standard code 16172:2014 Reinforcement Couplers for Mechanical Splices of Bars in Concrete- Specification.
- [31] International Organization of Standardization (ISO), Steel for the reinforcement of concrete—ribbed bars, 1991; p. 6935–2.
- [32] *Jack C. Mc Cormac, James K. Nelson* ,Design of reinforced concrete seventh edition according to ACI 318-05 code edition 2006.
- [33] *JAMES G. MACGREGOR*, Reinforced concrete mechanics and design sixth edition 2009.
- [34] *John Hicks*, Welded design theory and practice.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

- [35] *Keith L. Coogler, Kent A. Harries, Ph.d., P. Eng. Marcy Gallick, P.E.* Evaluation of offset mechanical reinforcing bar splice systems.
- [36] *Mashhour Ghoneim, Mahmoud El-mihilmy* ,Design of reinforced concrete structure second edition volume two 2008.
- [37] *Sindo Kou*,Welding metallurgy second edition.
- [38] *Singh R. Himanshu. K. Bhalla*, Reinforcement coupler as an alternative to lap splice volume two.
- [39] *Swami p. s, javheri s. b, mittapalli d. l, kore p. n.* Use of mechanical splices for reinforcing steel national conference on innovative trends in engineering and technology-2016.
- [40] *W.H. Mosley, R. Hulse and J.H. Bungey* ,Reinforced concrete design third edition 1987.

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

APPENDIX-A

A. Splicing of reinforcement

Provisions of EN -1992-1-1-2004 on development, anchorage and splicing of reinforcement

Ultimate bond stress

The ultimate bond resistance shall be sufficient to prevent bond failure and the design value of the ultimate bond stress, f_{bd} , for ribbed bars may be taken as:

$$f_{bd} = 2.25\eta_1\eta_2f_{ctd}$$

Where:

f_{ctd}	is the design value of concrete tensile strength
η_1	is a coefficient related to the quality of the bond condition and the position of the bar during concreting? $\eta_1 = 1.0$ when 'good' conditions are obtained and $\eta_1 = 0.7$ for all other cases and for bars in structural elements built with slip-forms, unless it can be shown that 'good' bond conditions exist
η_2	is related to the bar diameter: $\eta_2 = 1.0$ for $\phi \leq 32mm$ $\eta_2 = (132 - \phi)/100$ for $\phi > 32mm$

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Basic anchorage length

The calculation of the required anchorage length shall take into consideration the type of steel and bond properties of the bars.

The basic required anchorage length, $l_{b,req}$, for anchoring the force $A_s f_{yd}$ in a bar assuming constant bond stress equal to f_{bd} follows from:

$$l_{b,rqd} = \left(\frac{\phi}{4}\right) \left(\frac{\sigma_{sd}}{f_{bd}}\right)$$

where σ_{sd} is the design stress of the bar at the position from where the anchorage is measured from at the ultimate limit state.

Design anchorage length

The design anchorage length, l_{bd} , :

$$l_{bd} = \alpha_1 \alpha_2 \alpha_3 \alpha_4 \alpha_5 l_{b,rqd} \geq l_{b,min}$$

Where α_1 , α_2 , α_3 , α_4 and α_5 are coefficients given in Table below:

α_1	is for the effect of the form of the bars assuming adequate cover
α_2	is for the effect of concrete minimum cover
α_3	is for the effect of confinement by transverse reinforcement
α_4	is for the influence of one or more welded transverse bars ($\phi_t > 0.6\phi$) along the design anchorage length l_{bd}
α_5	is for the effect of the pressure transverse to the plane of splitting along the design anchorage length

The product $(\alpha_2 \alpha_3 \alpha_5) \geq 0.7$

$l_{b,min}$	is the minimum anchorage length if no other limitation is applied: <ul style="list-style-type: none"> - For anchorages in tension: $l \max\{0.3l_{b,rqd}; 10\phi; 100mm\}_{b,min}$ - For anchorages in compression: $l \max\{0.6l_{b,rqd}; 10\phi; 100mm\}_{b,min}$
-------------	---

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

The arrangement of lapped bars should comply

The clear transverse distance between two lapped bars should not be greater than 4ϕ or 50 mm, otherwise the lap length should be increased by a length equal to the clear space where it exceeds 4ϕ or 50 mm;

The longitudinal distance between two adjacent laps should not be less than 0.3 times the lap length, l_0

In case of adjacent laps, the clear distance between adjacent bars should not be less than 2ϕ or 20 mm.

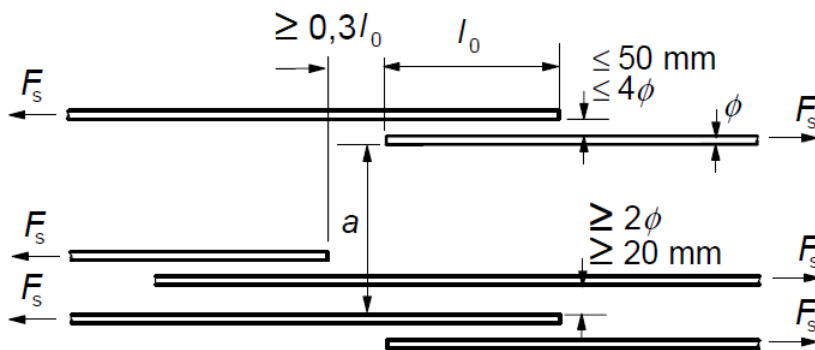


Figure: Adjacent laps

Lap length

The design lap length is:

$$l_0 = \alpha_1 \alpha_2 \alpha_3 \alpha_5 \alpha_6 l_{b,rqd} \geq l_{0,min}$$

Where:

$$l \max\{0.3\alpha_6 l_{b,rqd}; 15\phi; 200mm\}_{0,min}$$

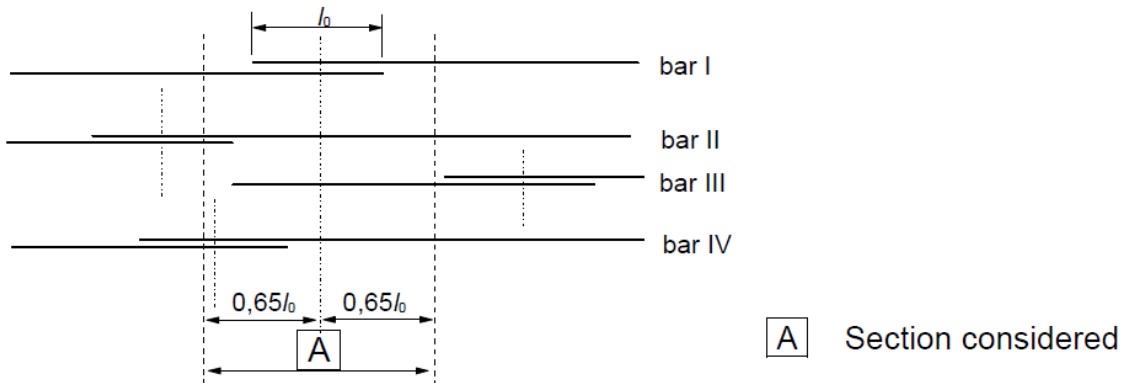
Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Values of $\alpha_1, \alpha_2, \alpha_3,$ and α_5 , may be taken from Table above; however, for the calculation of α_3 , $\sum \sum A_{st,min}$ should be taken as $1.0A_s \left(\frac{\sigma_{sd}}{f_{yd}} \right)$, with A_s = area of one lapped bar.

$\alpha_6 = \left(\frac{\rho_1}{25} \right)^{0.5}$ but not exceeding 1.5, where ρ_1 is the percentage of reinforcement lapped within $0.65l_0$ from the center of the lap length considered (see Figure below). Values of α_6 are given in the table below.

Table: Values of the coefficient α_6

Percentage of lapped bars relative to the total cross-section area	< 25%	33%	50%	>50%
α_6	1	1,15	1,4	1,5
Note: Intermediate values may be determined by interpolation.				



Example: Bars II and III are outside the section being considered: % = 50 and $\alpha_6 = 1,4$

Figure: Percentage of lapped bars in one section

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Calculate the minimum column lap length using EC2

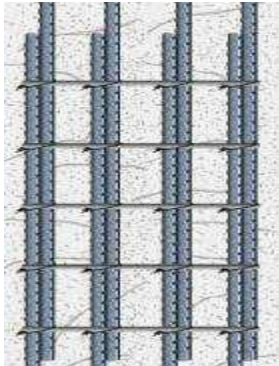


Figure. Column lap length

Design information

- C40/50 concrete
- 400 mm square column
- 45mm nominal cover to main bars
- Longitudinal bars are in compression
- Maximum ultimate stress in the bars is 390 MPa

$$l_0 = \alpha_1 \alpha_2 \alpha_3 \alpha_5 \alpha_6 l_{b,reqd} \geq l_{0,min}$$

Procedure

- Determine the ultimate bond stress, f_{bd} EC2 Equ. 8.2
- Determine the basic anchorage length, $l_{b,req}$EC2 Equ. 8.3
- Determine the design anchorage length, l_{bd}EC2 Equ. 8.4
- Determine the lap length, $l_0 = \text{anchorage length} \times \alpha_6$

Column lap length

Determine the ultimate bond stress, f_{bd}

$$f_{bd} = 2.25 \eta_1 \eta_2 f_{ctd} \dots \dots \dots \text{EC2 Equ. 8.2}$$

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

$\eta_1=1.0$ 'good' bond condition

$\eta_2=1.0, \phi \leq 32mm$

$f_{ctd} = \alpha_{ct} f_{ctk,0.05} / \gamma_c$EC2 Cl 3.1.6(2), Equ.3.1.6

$\alpha_{ct}=1.0, \gamma_c=1.5$

$f_{ctk,0.05} = 0.7 \times 0.3 f_{ck}^{2/3}$EC2 Table 3.1

$f_{ctk,0.05} = 0.21 \times 40^{2/3}$

$f_{ctk,0.05} = 2.456 \text{Mpa}$

$f_{ctd} = \alpha_{ct} f_{ctk,0.05} / \gamma_c = 2.456 \text{Mpa} / 1.5 = 1.637 \text{Mpa}$

$f_{bd} = 2.25 \times 1.637 \text{Mpa} = 3.684 \text{Mpa}$

Determine the basic anchorage length, $l_{b,req}$

$l_{b,req} = (\sigma_{sd} / f_{bd}) \times (\phi / 4)$ EC2 Equ 8.3

Max ultimate stress in the bar, $\sigma_{sd} = 390 \text{MPa}$.

$l_{b,req} = (\sigma_{sd} / f_{bd}) \times (\phi / 4)$

$l_{b,req} = 26.47\phi$

For concrete class C40/50

Determine the design anchorage length, l_{bd}

$l_{bd} = \alpha_1 \alpha_2 \alpha_3 \alpha_4 \alpha_5 l_{b,req} \geq l_{b,min}$EC2 Equ. 8.4

$l_{bd} = \alpha_1 \alpha_2 \alpha_3 \alpha_4 \alpha_5 (26.47\phi)$

For bars in compression $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 1.0$

Hence $l_{bd} = 26.47\phi$

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Determine the lap length, l_0 = anchorage length $\times \alpha_6$

All the bars are being lapped at the same section, $\alpha_6 = 1.5$

A lap length is based on the smallest bar in the lap, 25mm Hence,

$$l_0 = l_{bd} \times \alpha_6$$

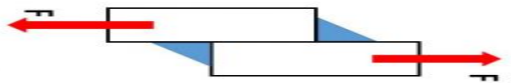
$$l_0 = 26.47 \text{ } \varnothing \times 1.5$$

$$l_0 = 39.71 \text{ } \varnothing = 39.71 \times 25$$

$$l_0 = 993 \text{ mm}$$

Weld lap force calculation

Determine the strength of a transverse fillet weld. A transverse fillet weld is one that is perpendicular to the force applied as seen in the image below.



The load carrying capacity of the weld is:

$$\sigma_t = \frac{F}{A}$$

σ_t is the tensile strength of the weld (determined by the filler metal being used).

F is the force the weld can handle, in other words, the strength of the weld in lbf

A is the effective area of the weld

First, determine the throat size. Throat = $x \cos 45^\circ = (1/4) \times (0.707) = 0.177$ "

Now determine the effective area of the weld. Two 20-inch long welds.

Effective Area = 2 \times length \times throat = (2) \times (20) \times (0.177) = 7.08 sq-in

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Now we go back to our main formula.

Using an ER70S-6 wire, is equal to 70,000 psi, Rearrange the formula to solve for F.

$$F = \sigma_t \times A$$

$$F = (70,000) \times (7.08) = 495,600 \text{ lbf}$$

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

APPENDIX-B

B. Concrete mix design procedure

Trial mix design was prepared using ACI mix design manual for C-25 concrete. In this research ACI mix design manual was used for trial mix design preparation for C-25 concrete.

Specified information:

Strength of concrete: 25 MPa

Cement type: 42.5 OPC and 32.5 PPC

Max aggregate size: 19/20mm

Aggregate type: crushed

Slump: 25-50mm

Air entrainment: None

Standard deviation: Unknown

Min cement content: 300kg/m³

Max. Cement content: 550 Kg/m³

Max free w/c ratio: 0.65

Step 1: Slump Value

Slump=50mm (25-50mm) ----- [Table A1.5.3.1 [85]]

Step 2: Maximum aggregate size

Aggregate size = 20mm (19mm)

Step 3: Mixing water and air content

Water content =190kg/m³----- [Table A1.5.3.3 [85]]

Air content = 2%-----[Table A1.5.3.3 [85]]

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Step 4: Water-Cement ratio

W/C = 0.61 ----- [Table A1.5.3.4(a) [85]]

0.61 < 0.65 (Maximum Required), Take 0.61

Step 5: Cement Content

Cement Content = $190/0.61 = 311 \text{ kg/m}^3 > 300 \text{ kg/m}^3$ (minimum required), Take 311 kg/m³

Step 6: Content of coarse aggregate

Fineness modulus of fine aggregate = 2.62

Maximum size of coarse aggregate = 19mm, by interpolation approximate value of percentage of coarse aggregate = 0.638----- [Table A1.5.3.6 [85]]

Therefore, weight of coarse aggregate is $0.638 * 1574 = 1004 \text{ kg/m}^3$

Step 7: Content of fine aggregate

Absolute volume basis

Volume of air $2/100 = 0.020 \text{ m}^3$

Volume of water $190/1000 = 0.190 \text{ m}^3$

Volume of cement $311/3.15 \times 1000 = 0.099 \text{ m}^3$

Volume of coarse aggregate $1004/2.70 \times 1000 = \underline{0.372 \text{ m}^3}$

Total 0.681 m³

Volume of fine aggregate = $1 - 0.681 = 0.319 \text{ m}^3$

Therefore, weight of fine aggregate = $0.319 \times 2.63 \times 1000 = 839 \text{ kg/m}^3$

Assessment of Locally Produced Mechanical Coupler and Traditional Reinforcement Splice System in Building Construction

Step 8: Adjustment

Absorption Capacity of fine aggregate = 2.04%

Moisture Content of fine aggregate = 2.04%

Absorption Capacity of coarse aggregate = 0.80%

Moisture Content of coarse aggregate = 1.01%

The absorption capacity and moisture content of fine aggregate are equal. Therefore, adjustment for coarse aggregate.

Coarse aggregate (Wet) = $1004\text{kg} + 1004\text{kg} \times (0.0101 - 0.008) = 1006\text{kg/m}^3$

Water = $190\text{kg} - 1004\text{kg} \times 0.0021 = 188\text{kg/m}^3$