Epoxy Jointed Laps in Steel Reinforcement for RC Beam

by

Mimi Nur Laily Binti Majid

Dissertation submitted in partial fulfillment of
the requirements for the
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CERTIFICATION OF APPROVAL

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Civil Engineering Program
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Approved by,

(Assoc. Prof. Dr. Nasir Shafiq)

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JANUARY 2006

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(MIMI NUR LAILY BINTI MAJID)

ABSTRACT

This report analyzes the effectiveness of epoxy jointed steel bar laps for bending capacity of RC beams. The objective of this study was to determine the pullout strength of different epoxy jointed steel laps length and to determine the flexural strength of epoxy jointed lap in RC beam with the most optimum lap length using Universal Testing Machine. Standard steel bar size of 12mm diameter and concrete mix proportion of 1(cement):2.33(fine aggregate):3.5(coarse aggregate) with a water/cement ratio of 0.55 were applied throughout this study. As the material of study, high strength adhesive for bonding reinforcement from SIKA called Sikadur-30 was used. The development of tension laps length were 10 Φ (120mm), 15 Φ (180mm) and 20 Φ (240mm) by which the epoxy jointed beams were compared for its strength to continuous tension steel reinforcement beams. With the optimum lap length obtained for epoxy jointed steel bar lap, construction error due to shortened lap length designed could be rectified and steel wastage at construction site could be minimized by joining two to three steel bars of insufficient length together to produce one continuous steel reinforcement.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Concrete is good to take high compression loads but is poor in tensile loading. Therefore reinforcement bars are provided as per designed load calculations for reinforced concrete structures. The reinforcement bars are generally steel bars, available in various standard sizes and lengths. But, there are limitations on the length of reinforcement bar that is suitable for transportation to the site and handling. Therefore, for the purpose of giving continuity to the reinforcement provided in reinforced concrete structures, it is required to splice these reinforcement bars in such a way that the desired continuity is achieved.

In construction industry, the simplest way of splicing the bars for continual load transfer is to lap them. The other method could be by welding or mechanical devices. A properly designed splices of reinforcing bar are the key element in transmitting forces through the structure and creating a solid unit.

Aligned with the development of science and technology, an adhesive joint is now popular in load bearing engineering situations which can withstand many years of use. With the detailed study on the effectiveness of epoxy jointed steel bar laps, an economically, safe and successful adhesively bonded steel bar laps joint was designed.

1.2 Problem Statement

In Malaysia, building structural drawings are based on British Standard Institution (BSI). Table 3.29 in BS 8110 describes the lap length for steel bar lapping (refer Appendix 1). The lapping is designed with adequate length as it will transfer as much load as a continuous steel reinforcement [1].

During construction, the contractors sometimes do mistake on designing the steel reinforcement. The lap lengths are sometimes shorter than in the structural plan and it could cause severe cracking on the building later on because the beams are not capable in fully transferring the loads. The cost and time taken for the contractors to redo the steel reinforcement will be reduced as there is an applicable method that could rectify this error easier. By varying the development length of epoxy jointed steel bar laps, the optimum lap length will be identified and with that, the shortened splices may no need to be redo as Sikadur-30 may help in strengthening the spliced.

At construction site, there are lots of waste steel bars due to insufficient length to be used according to the standard. Through this study, it was expected to get used these bars by joining two to three bars together and produce another one continuous steel bar thus minimizes the steel wastage.

1.3 Objectives

While the advantages and limitations of conventional splicing methods are well established, the performance of epoxy resin in civil engineering applications needs further investigation. Properly designed of the splicing can provide superior structural enhancement while complementing existing construction industry practices.

The overall scope of two semesters experimental investigation was to measure the effectiveness of epoxy jointed steel bar lap for bending capacity of RC beams by:

1. determine the pullout strength of different epoxy jointed steel bar laps length
2. determine the static flexural strength of RC beam with the most optimum epoxy jointed laps length.

1.4 Scope of Study

The study involved researches from engineering standards, journals, books and internet literature which are related on the use of epoxy in construction. The effectiveness of epoxy jointed steel bar laps were measured by laboratory testing consist of nine samples of epoxy jointed steel bar laps for Pullout Strength Test to determine the bonding characteristics of Sikadur-30 with the steel bar and twelve samples of RC beams for Static Flexural Strength Test to measure the bending capacity of epoxy jointed laps of RC beam.

This study determined the optimum lap length of 12mm steel bar diameter and the other standardizations were stated as below:

1. Pullout Strength Test
    - i. steel length of 400mm each (refer 3.2.1)
    - ii. grip distance 350mm

2. Static Flexural Strength Test
    - i. concrete mix proportion of 1:2.33:3.5 with w/c 0.55.
    - ii. link size of 6 mm
    - iii. beam size 150mm x 150mm x 750mm
    - iv. curing of beams for 28 days

CHAPTER 2

LITERATURE REVIEW

2.1 Sikadur®-30

Sikadur-30 was used as the adhesive or fastener for bonding reinforcements. Sikadur-30 is a thixotropic adhesive mortar based on a 2-component solvent free epoxy resin. Sikadur-30 is used primarily to bond structural reinforcements to other substrate. It can also be used to bond and fill a wide variety of building and construction materials. Some of the advantages of Sikadur-30 are it has a high creep resistance under permanent load, has a good mechanical strength and chemical resistance, has a low shrinkage during curing time, has a high in abrasion resistance, high early strength, high tensile and flexural strength and has an excellent adhesion to most building materials even when damp.

For the application of this adhesive, the steel surface to be bonded must be clean, sound and free from dust, oils, grease, free from any paints, rust and oxide films by grit blasting. Sikadur-30 is supplied in factory proportioned units comprising the correct quantities of Part A (Resin) and Part B (Hardener). Part B component need to be decanted into Part A and mixed thoroughly until a uniform color is achieved (3 minutes). The Sikadur-30 must be applied to the steel without delay.

Technical specifications for Sikadur®-30 are appended in Appendix 2.

Sikadur®-30 research and application

1. The Application of Adhesives to Connect Steel Members [2]

Adhesives are used in very different applications. Up to now the technique of structural adhesive bonding is not applied to steel constructions. This article shows adhesives to be efficient. The application of adhesives in steel constructions is possible and can be an alternative on its own to common techniques like bolts and welds as well as in combination with bolts.

Normally, steel members are connected with the help of bolts (in the past: rivets) or welds. In the 1960ies, some bridges were built with adhesive connections. There are, however, additional bolts for the sake of safety. Since there was no knowledge of calculation, the construction and design of these buildings were based on tests. Up to now, the bridges do not have any damages. This shows a sufficient long-lasting behavior of adhesives. Meanwhile the quality of adhesives has been very much improved. There are special adhesives for various possibilities of application. Above all, the car and airplane industries are using adhesives to connect aluminium or steel–so why not the steel manufacturers? Adhesive connections can be an alternative to common techniques like welds, bolts or rivets. Until now the adhesive connection is not used because of a lack of knowledge about the mechanism and design calculation, the long-time resistance as well as the working of the sticking surfaces. For applications, an adhesive with suitable strength and long-time resistance must used. The technique has to be handled easily during the manufacturing of the steel construction.

Several tests of adhesive connections were carried out. In the first test series, different adhesives were used under various loads. The adhesives tested were not selected for special characteristics, but were free-samples. The second test series contains combined connections, bolts and adhesives.

The test results show the possibility of adhesive connections in steel constructions. In comparison to bolted connections adhesive connections show higher strength and stiffness. The main problems of adhesive connection are the abrupt failure and the long-time behavior. The adhesive layer increases the stiffness and reduces the peaks of stress in combined connections. The safety is guaranteed by the bolts. The preloading of the bolts has no influence on the carrying capacity and stiffness of a combined connection. Adhesives are an alternative to the common techniques to connect steel members. It is necessary to create a base of calculation for practical applications.

2. The Use of Sikadur® Adhesives for Pipeline Connection Assemblies in Changi Water Reclamation Plant, Singapore [3]

Singapore's Deep Tunnel Sewerage System (DTSS), when fully completed, will replace the existing sewerage system which dates back to 1960. DTSS will consist of two large bore, deep tunnels that crisscross the island, two water reclamation plants and two deep sea effluent pipelines.
Some 100km of tunnels, with diameters of up to 6.5m, will be constructed at depths between 20m and 60m, and will carry sewage and waste water by gravity to the reclamation plants at Changi and Tuas, both built on reclaimed land.

Straub Werke AG, Switzerland, was awarded the contract to join together these major steel pipes with their connection system designed specifically for this purpose. The sewage pipes were made of steel and were up to 4 meters in diameter. The ends of the pipes could not be aligned precisely enough for standard pipe connection systems and they were not perfectly circular at the ends once installed. (See pictures below)

To make the pipe connections so that they were level and so that their long term integrity could be assured even under pressure, both of these deviations had to be compensated for.

Figure2.1: The problem with the existing situation on site

To achieve the necessary alignment of the pipe ends with each other, and to compensate for the shape, it was decided to apply a band of Sikadur®-30 (2 part epoxy adhesive mortar) around the whole of the perimeter of the steel pipe, onto which the pipe connection could then be fitted. The layer thickness of the Sikadur®-30 had to be carefully adjusted on each section of the pipes circumference to match the deviation of the pipes to be connected.

Preliminary tests were carried out by Straub in Switzerland. Sikadur®-30 was applied on a steel pipe with a much smaller diameter and the connection was installed after it had cured. Leak tests were then carried out at the design water pressure.

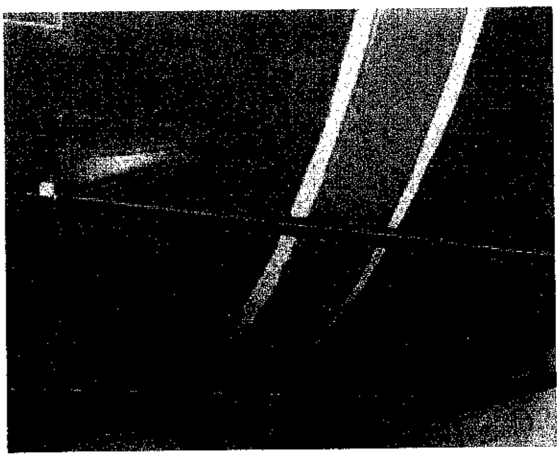


Figure 2.2: The connection assemblies after installation on the project

As the solution, Straub Werke AG was provided with a relatively simple solution to adapt the tolerances and unevenness of the pipes without having to mechanically machine or refabricate the pipes. After surface preparation by blast cleaning the local areas of the steel pipes, the Sikadur®-30 was applied, and it proved Sikadur®-30 was able to provide a level base for the connection assemblies to be seated on top.

2.2 Steel Splicing

The easiest, cheapest and regularly used of connecting the rebar are by lapping. A lap is when two pieces of rebar are overlapped to create a continuous line of rebar. The length of the lap varies depending on a number of things, including the concrete strength, the rebar grade, size, and spacing. Contact splices, Figure 2.3 which bars touch each others are preferred because they are more secure against displacement. The effective lapping distance has been study and is specified in Table 3.29 BS 8110. They should be placed, if possible, away from points of high stress. The steel lap strength may be affected by the way the steels are bonded (welding or adhesive-bonded) and types of steel joining (singly lap, butt strap, scarf, etc).

When there is not enough space to do a lap splice, mechanical or welded splices are often used. In general, Concrete Reinforcing Steel Institute (CRSI) recommends against manual arc welding in the field. However, if necessary, field-welded splices are accomplished by electric arc welding the butts of the reinforcing bar together. Welding should conform to ANSI/AWS D1.4-92, *"Structural Welding Code Ð Reinforcing Steel"* of the American Welding Society. CRSI recommends against connecting crossbars by small arc welds, known as "tack welds." Tack welding is a factor associated with brittle failure of reinforcing bar assemblies. For mechanical splicing, couplers are used to transfer tension and/or compression forces and end-bearing devices for compression forces transfer.

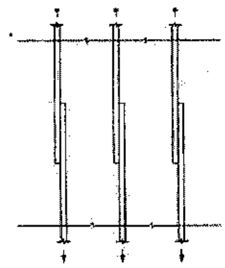


Figure 2.1: Contact Lap Splices

The reinforcing steel must be cleaned of all dirt, oil, and grease. The steel bar must be tied together sufficiently so that each bar will retain on its proper position after encasement. Reinforcing steel must be located at the specified distance from the surface in order for reinforced concrete members to have the proper clearance. Reinforcement shall be placed in the position shown on the plans and kept in that position while the concrete is being placed. To attempt to position a reinforcing bar cage during or after depositing of the concrete is not permitted due to the fact that the consolidation of the concrete around the perimeter of the reinforcing steel will be compromised.

2.3 Pullout Strength Test

Pullout Strength Test for epoxy jointed steel bar lap is the measure of how well the bonding of Sikadur-30 to the steel bars. In this test, tension forces were applied at both end of epoxy jointed steel samples at a rate of 10mm/min. From this test, the bonding capacity of the adhesive to the steel bars was known through the Rm/Re ratio which was the ratio of Universal Tensile Strength to Yield Strength of the steel bar.

2.4 Static Flexural Strength Test

Flexural strength is the measure of how well a material resists bending, or what is the stiffness of the material. In flexural testing the force is applied at mid-span direction (see Figure 2.4). On a standard testing machine, the loading nose is pushed onto the beam sample at a constant rate of 2mm/min.

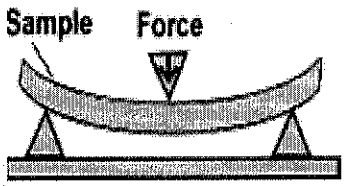


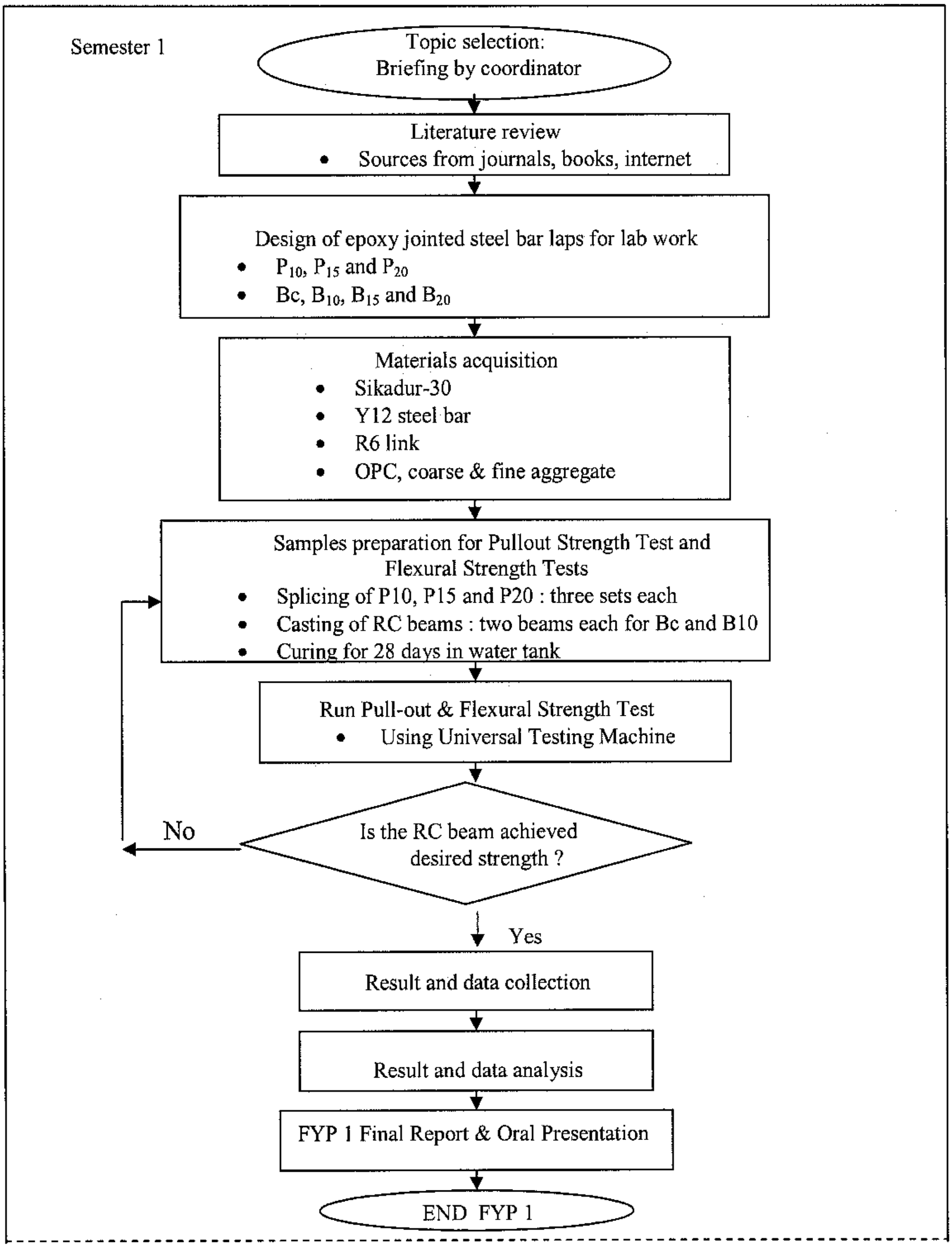
Figure 2.4: Flexural test with mid point loading

The flexural modulus (ratio of stress to strain) is most often quoted when citing flexural properties. Flexural modulus is equivalent to the slope of the line tangential to the stress/strain curve, for the portion of the curve where the plastic has not yet deformed.Values for flexural stress and flexural modulus are reported in MPa.

CHAPTER 3

METHODOLOGY

3.1 Methodology Flow Chart



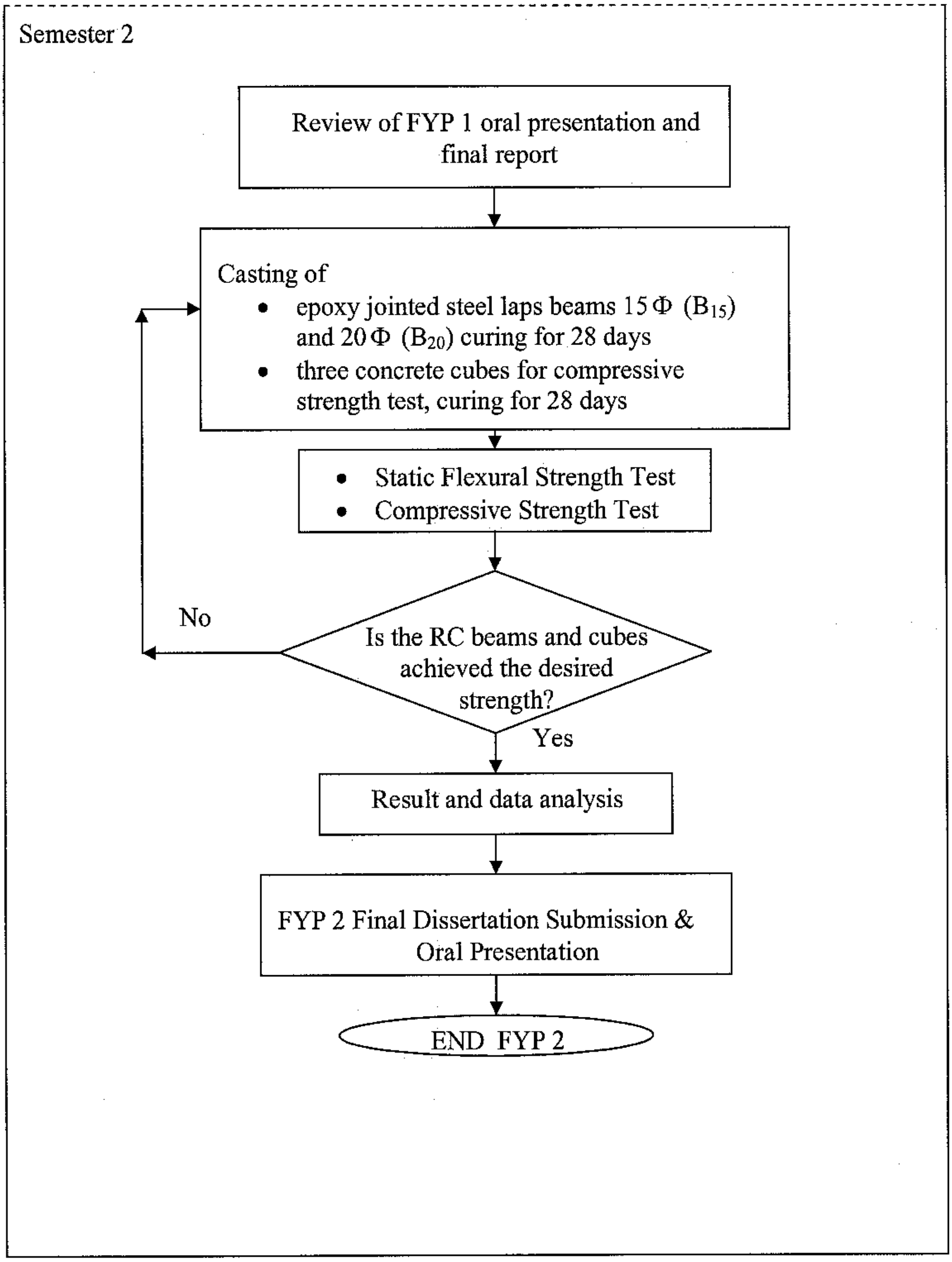


Figure 3.1: Flow Chart Diagram defining the methodology of this study

3.2 Project flows and specifications

The Universal Testing Machine was used for the Pullout and Static Flexural Strength Test.

Figure 3.2: Universal Testing Machine for Pullout and Static Flexural Strength Test

3.2.1 Samples Preparation for Pullout Strength Test

For samples preparation of Pullout Strength Test, the steps below were followed:

1) 400mm length of steel bars were cut, two for each sample
2) Any rust from the steel bars were cleared using sand paper
3) Sikadur-30, Part A : Part B to 3 : 1 were mixed thoroughly
4) The mixed Sikadur-30 was applied to both surfaces of the steel bars to its specified length
5) The epoxy jointed steel bars were jointed together without delay
6) Three samples for each lap length were prepared
7) The samples were left at room temperature for three days before testing

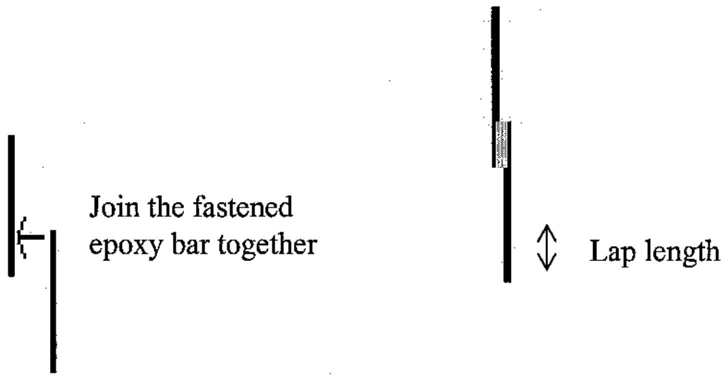


Figure 3.2: Samples preparation of Pullout steel bar

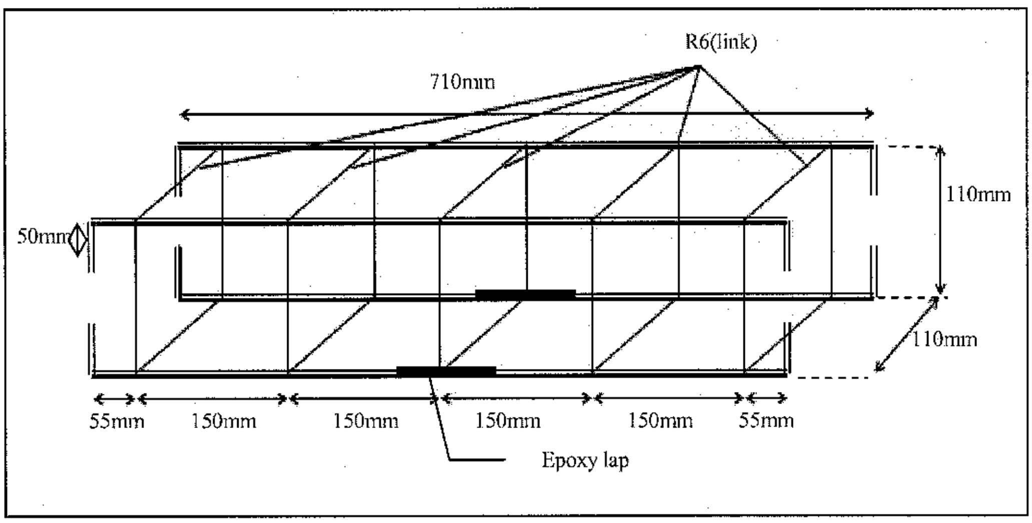
Table 3.1: Specification for pullout strength test

No.	Notation	Lap length (mm)	No of samples
1	$10\Phi = P_{10}$	$10\ \Phi = 120$	3
2	$15\Phi = P_{15}$	$15\ \Phi = 180$	3
3	$20\Phi = P_{20}$	$20\ \Phi = 240$	3

3.2.2 Beams Preparation for Static Flexural Strength Test

For the flexural strength of RC beam, a total of eight beams were cast with a different lap length for tension reinforcement. Figures and table below show the detail drawing and specification of the sample beams.

a)



b)

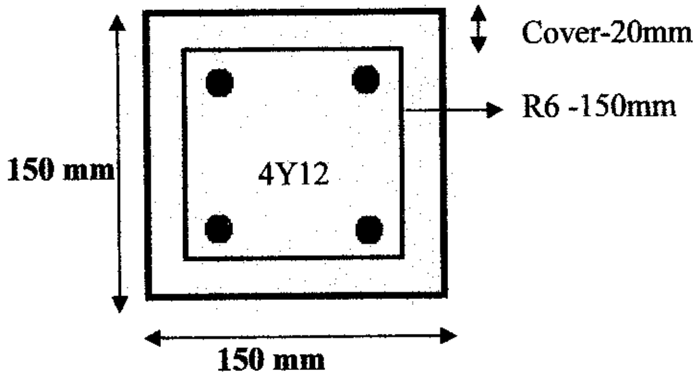


Figure 3.4a&b: Steel reinforcement detailing for beam samples

A beam mould of 150mm x 150mm x 750mm was used for the experiment. The lapping steels were positioned at the bottom of the beam as the beams were tested under its tension capacity. In BS 8110 Clause 3.12.8.9, the connection transferring stress should be placed, if possible, away from points of high stress. For the worst condition, the beams were lapped at the center of the beams at a prescribe lap length.

Figure below shows the design of 120mm tension epoxy jointed steel bar lap with continuous compression steel bars.

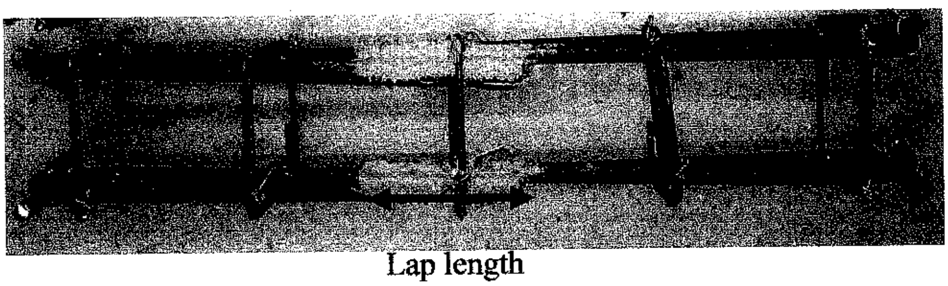


Figure 3.5: Sample of epoxy jointed steel reinforcement laps

Table 3.2: Sample Beams Specifications

No	Notation	Tension Steel Lap length (mm)	No of samples
1	Control beam B_C	-	3
2	$10\Phi = B_{10}$	120	3
3	$15\Phi = B_{15}$	180	3
4	$20\Phi = B_{20}$	240	3

For Static Flexural Strength Test, 3 beams of continuous tension steel bars acted as the control beams and nine samples of varies epoxy jointed steel bar lap beams. The epoxy jointed beams were compared in terms of its strength to be as strong as the continuous beams. Control beams were noted as B_C, 120mm lapping, 180mm lapping and 240mm lapping were noted as B_{10}, B_{15} and B_{20} respectively.

Concrete mix ratio of 1(cement) : 2.33(fine aggregate) : 3.5(coarse aggregate) with a water cement ratio of 0.55 were used as a standard mix design for beams. Three concrete cubes were cast to determine the compressive strength of the concrete. All the calculations about the mix design were calculated in Appendix 3.

A standard casting procedure was followed to produce a standard concrete mix for all beams with 20mm (see Figure 3.5). Vibrator was used to produced a dense and non-honeycomb concrete. The beams then were stripped after 24 hours and cured for 28 day in water tank before the beams were tested for their flexural strength.

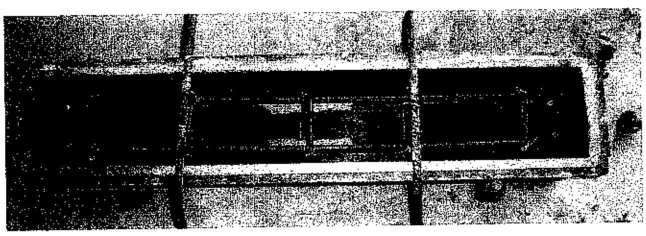
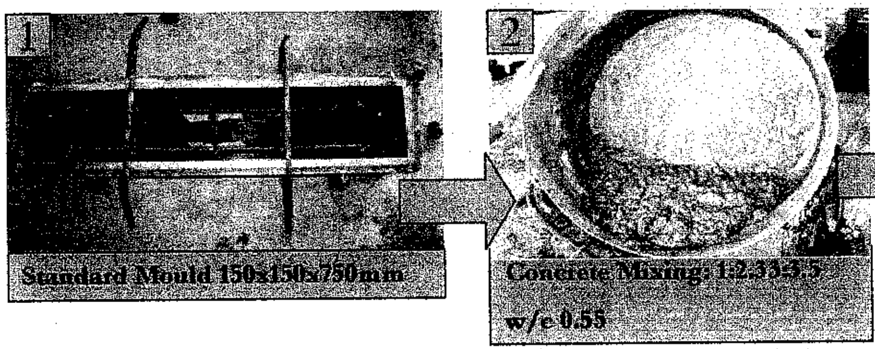
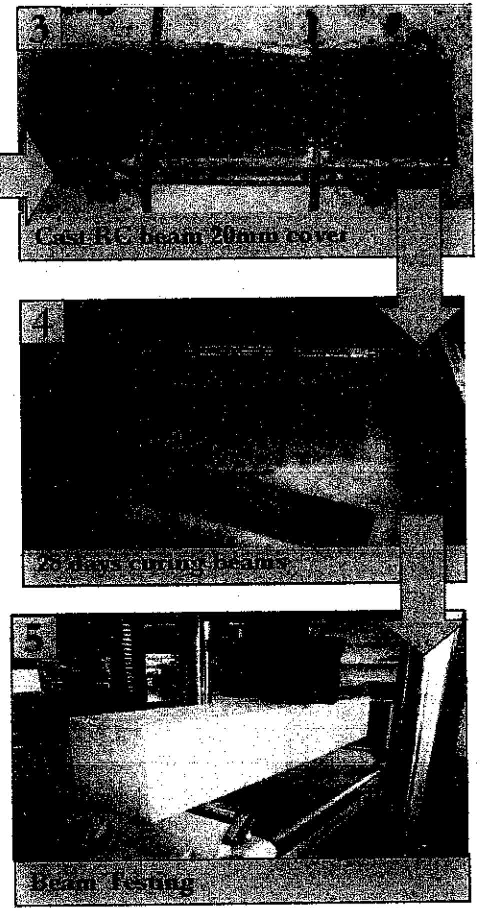


Figure 3.6 : Standard Beam Mould with 20mm Reinforcement Cover

Flexural Strength Test Samples Preparation





No	Notation	Lap Length (mm)
1	Control Beam B_C	Continuous rebar
2	10 ø = B_{10}	120
3	15 ø = B_{15}	180
4	20 ø = B_{20}	240

3.3 Tools

Samples preparation and laboratory testing were done in the Concrete Laboratory using equipment provided in the lab. The equipments used for samples preparation were moulds for beam casting, concrete mixer, vibrator, and for testing Compressive Strength Universal Testing Machine for Pullout and Static Flexural Strength Test was used.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Results

4.1.1 Compressive strength test

The average compressive strength of concrete cube with mix ratio 1:2.33:3.5, w/c 0.55 for 28 days curing was 40.32 MPa.

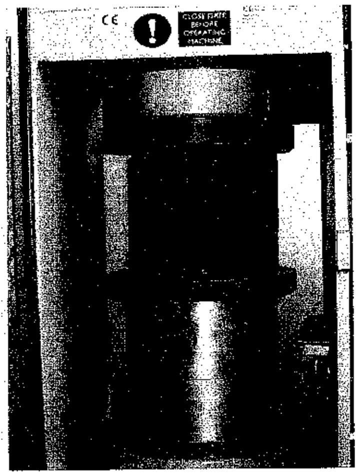


Figure 4.1: Compressive Strength Test of concrete cubes

4.1.2 Pullout Test Result

Table 4.1 shows the result of the pullout test of the epoxy jointed laps. Load versus stroke graphs for the samples are shown in the Appendix 4.

Table 4.1: Pullout Test Result

Test No	Max. Load (kN)	Universal Tensile Strength (MPa)	Yield Strength (MPa)	Ratio Rm/ Re (UTS / Yield Strength)
$P_{10\ Average}$ = 120mm lapping	8.74	64.70	64.42	1.005
$P_{15\ Average}$ = 180mm lapping	10.94	74.54	70.51	1.066
$P_{20\ Average}$ = 240mm lapping	10.52	63.02	62.70	1.005

4.1.3 Flexural Strength Test Result

Table 4.2 below shows the result of the static flexural strength test. The stress versus strain graphs for each beams are shown in the Appendix 5.

Table 4.1: Static Flexural Strength Test Result

Beam	Max Load (kN)	Max Stress (MPa)	Deformation at break (mm)	Strain at break (%)	Yield Strength (MPa)	Young's Modulus (MPa)
Average B_C= Control Beam	*83.165*	*27.72*	*12.96*	*1.73*	*26.465*	*5747.98*
Average B_{10}= 120mm lapping	*73.79*	*24.595*	*4.94*	*0.66*	*21.185*	*6662.59*
Average B_{15}= 180mm lapping	77.86	25.95	12.59	1.68	24.59	5994.24
Average B_{20}= 240mm lapping	79.85	26.62	21.78	2.90	23.88	7707.53

4.2 Discussion

4.2.1 Pullout Test

The epoxy jointed steel bar laps were introduced to tension forces (see Figure 4.2) through the grip of UTM machine.

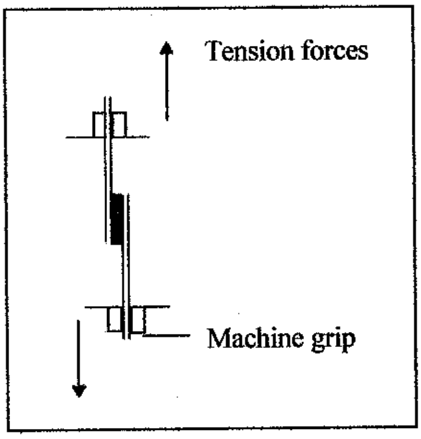


Figure 4.2: Sample under tension forces

Failure Mode

In general, steel will fail at the weakest point of the steel continuity. From the pullout test done, the epoxy jointed laps failed at the epoxy bonding rather than within the steel itself (see Figure 4.3).

Figure 4. 3: Broken epoxy jointed steel bar lap after Pullout Test

Essentially, the adhesive technique is a positive substance jointing [2]. The additional material – the adhesive - is needed to connect two sections. The active cohesive and adhesive forces in an adhesive layer are responsible for the strength (Figure 4.4).

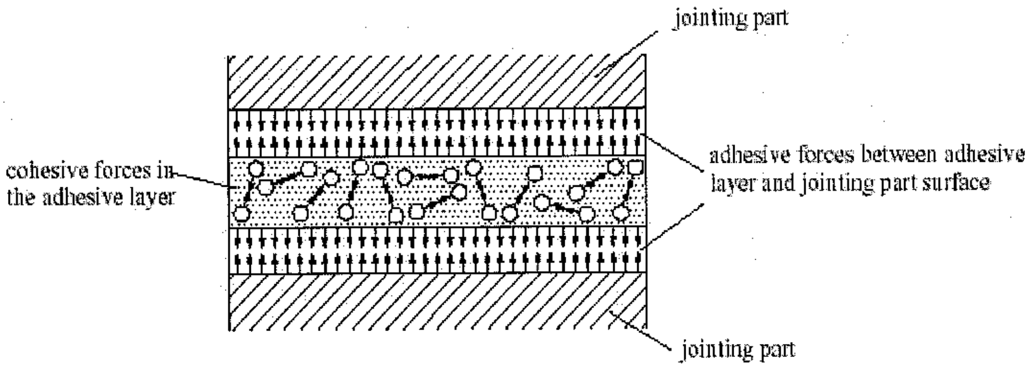


Figure 4.1: Adhesive and cohesive forces in an adhesive sealing

If one of the both forces or both will be exceeded due to stress, the adhesive connection fails. If "internal forces" are exceeded, the fracture will occur in the adhesive layer. This is a cohesive crack. The adhesive forces are effective between the adhesive layer and the jointing part surface. An adhesive crack occurs when there is a separation between the both materials. Another possibility of failure mode is the occurrence of cohesive and adhesive cracks at the same time (Figure 4.5).

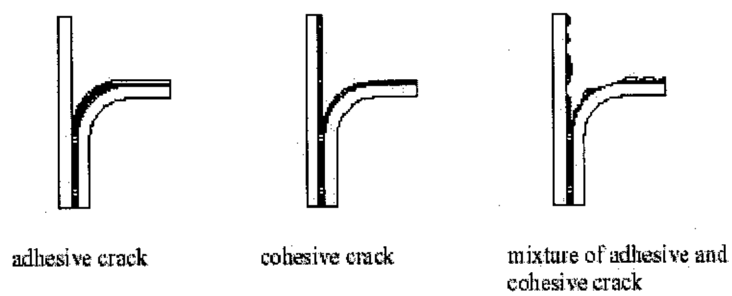


Figure 4. 2: Crack types

Graphs in Appendix 4 are graphs of Load (kN) versus stroke (mm) from the Pullout Strength Test done. From the pullout test, values of Universal Tensile Strength, Yield Strength and the Rm/Re ratio of the epoxy jointed steel laps were identified.

Theoretically, longer the lap length, the stronger the reinforcement will be. From the below bar charts, P_{15} with 180mm lapping gave the highest load taken, highest Universal Tensile Strength value, highest Yield Strength and the highest Rm/Re ratio which is the ratio of Universal Tensile Strength over Yield Strength.

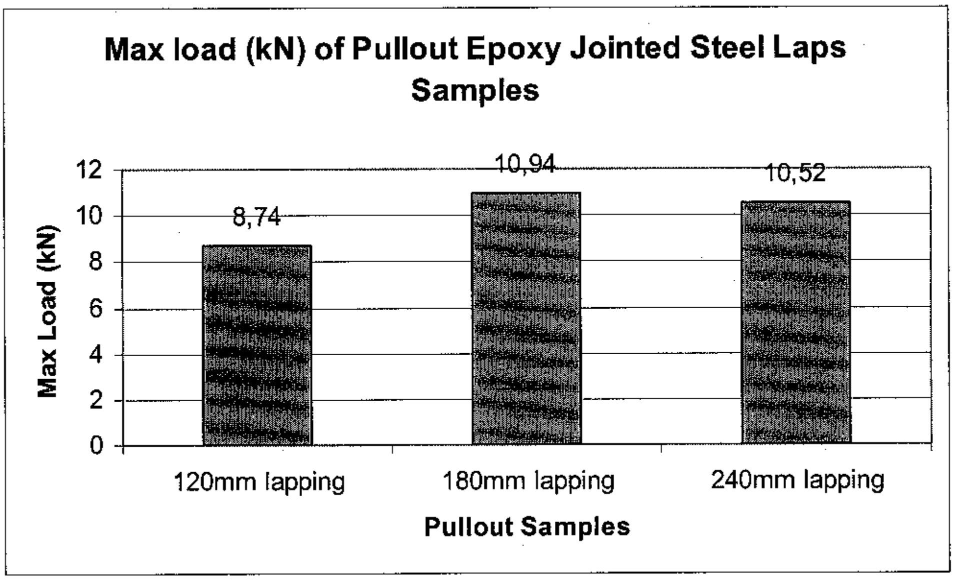


Figure 4.3: Maximum load of Pullout Samples

Figure 4.6 shows how much loading the samples could take before the sample fail. 180mm lapping gave the highest load taken by the pullout samples.

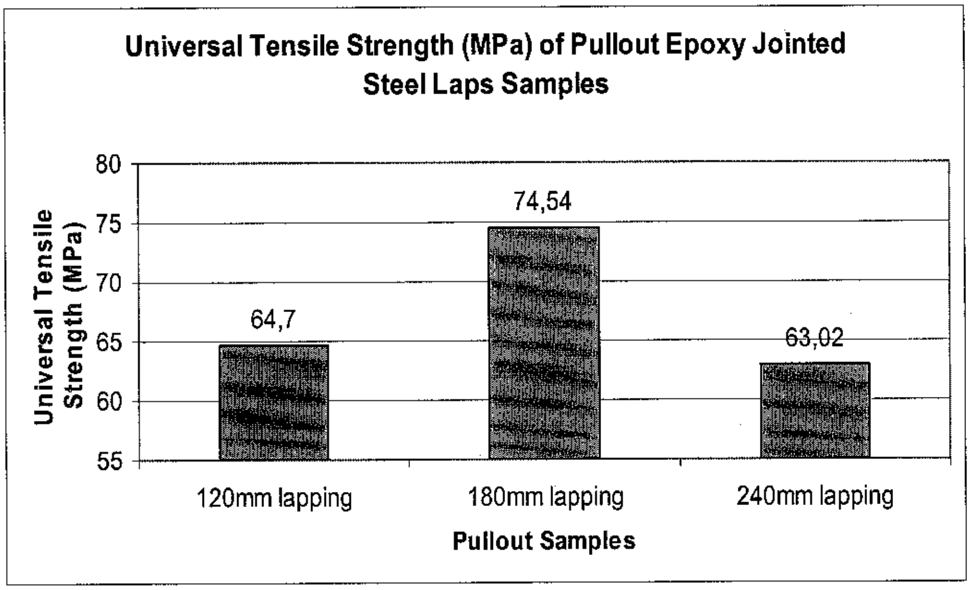


Figure 4.7: Universal Tensile Strength of Pullout Samples

Figure 4.7 is the Universal Tensile Strength of the samples. At this condition, the tensile strength was referred to the bonding strength of Sikadur-30 to the steel bars. Longer epoxy lapping should gives the better bonding strength but in this case180mm lapping, gave the highest value as compared to 240mm lapping may be due to the quality of the pasting.

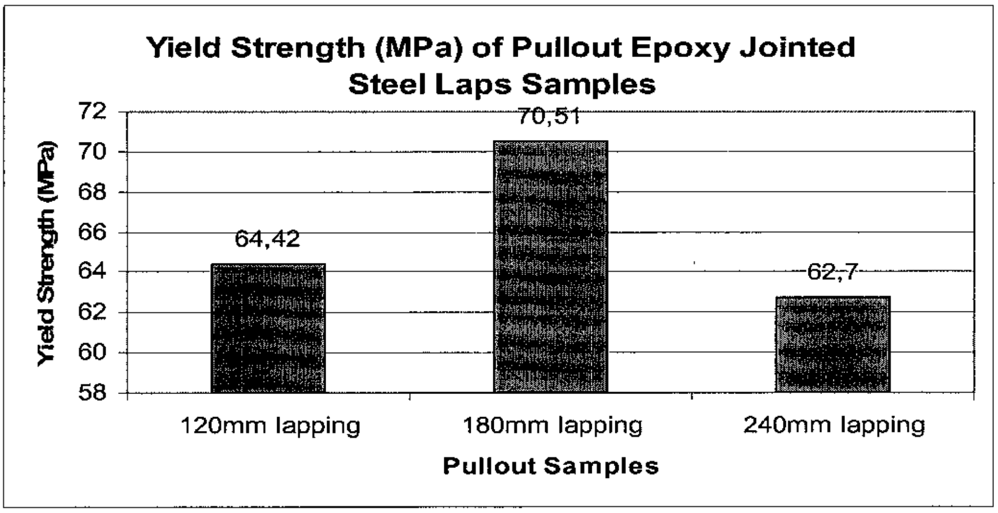


Figure 4.8: Yield Strength of Pullout Samples

Figure 4.8 shows the yield strength of the samples. Yielding of the same fabricated steel should be the same but, due to the difference in epoxy lapping, the strength varies with each others. 180mm lapping gave the highest value of yield strength.

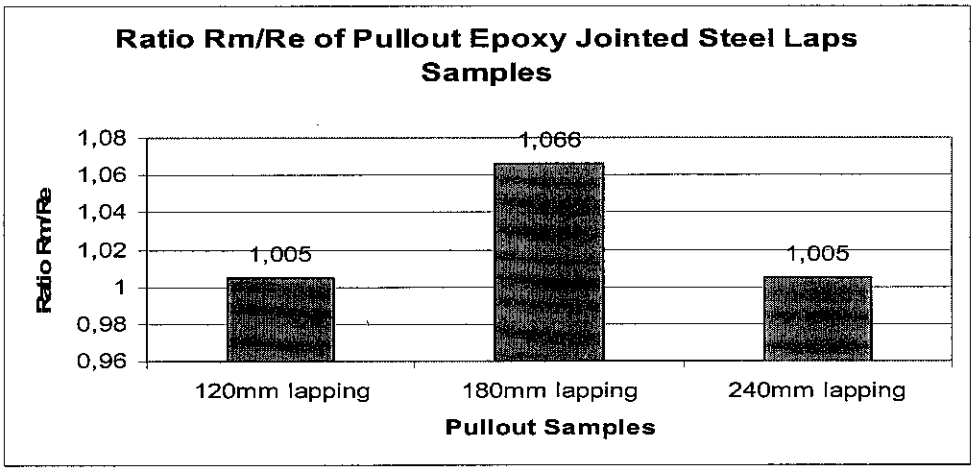


Figure 4.9: Rm/Re Ratio of Pullout Samples

Figure 4.9 shows the ratio of universal tensile strength to the yield strength of the samples. 180mm lapping gave the highest value of Rm/Re.

Advantages and Disadvantages

In adhesive technique, there is a uniformly distributed transmission of forces causing at the same time a uniformly distribution of stress vertical to the loading plane. Figure 4.10 shows welding and adhesive stress distributions. The stress distribution by welding depends on the quality of the weld [2].

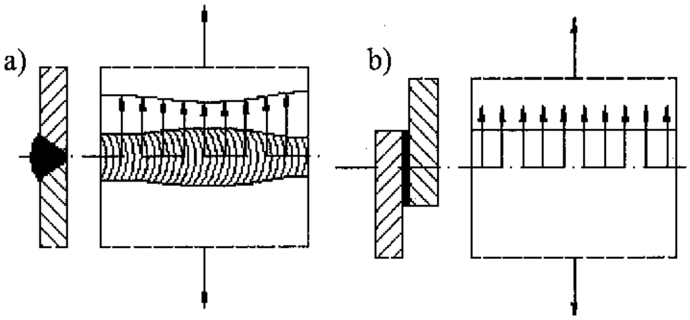


Figure 4.10: Stress distributions of different jointing a)welding b)adhesive

There are, however, disadvantages as well. A loss of strength was possible due to many influences. The failure at bonding of epoxy to steel bar proved that Sikadur-30 is a brittle material. The strength of epoxy jointed steel bars depended on the way the rebar were jointed; thicker the epoxy paste, stronger the splicing but it may reduced in bonding of concrete-rebar. The strength of the epoxy jointed lap was also depending on the bonding of the epoxy paste to steel bar surfaces. The steel surfaces must be cleaned, free from paints, oil and rust which will interfere the bonding of epoxy paste to the steel reinforcement. It is necessary to prepare the jointing surfaces and a definite time is required which is at least for the curing of the adhesive in order to get a sufficient strength.

4.2.1 Flexural Strength Test

All beams were tested for flexural strength by positioning the beams in simply supported position with a point load acting at the midpoint of the beam as Figure 4.11 below. A constant force was applied through the force nose until the beam failed by the automatic repulsion of the force nose.

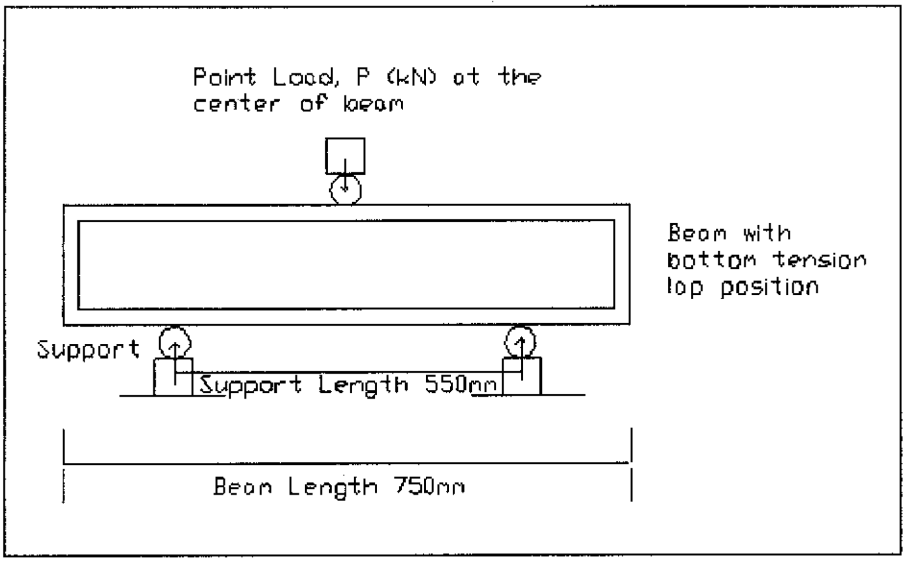


Figure 4.11: Flexural Strength Test Component

Graphs in Appendix 5 are the Stress (MPa) versus Strain (%) or known as Stress-Strain curve. Stress is a measure of the force per unit area (or force divided by area) acting in a member, and strain is a measure of the deformation of a member per unit length (or deformation divided by length). The two are related and are accountable for determining the strength and the stiffness of structural members and system [4].

A member is in tension when the force causes it to stretch or increase in length. The resulting stress is tensile stress, and the unit increase in length is tensile strength. A member is in compression when the force causes it to shorten or decrease in length. The resulting stress is compressive stress and the unit decrease in length is compressive strain. These definitions assume that the forces act through the centroid of the members. In practice, the forces do not always act through the centroid of members, resulting in the introduction of shearing and bending stresses and strains. It is necessary to determine the stresses and strains in the structural members and systems to assure that the individual members and the whole systems can meet the strength demands and the deflection limitations of the design criteria safely.

Point A in the graphs is the Yield Point of the beam, the point where the material begins to have permanent (unrecoverable) deformation. Point B is the Universal Tensile Strength point where stress at the highest point and it is the limit stress at which the material actually fractures, with sudden release of the stored elastic energy (released as noise and/or heat and/or more cracks e.g. for brittle materials). Point C is the break point when the beams fails and has no more energy to resist the applied load.

Failures of the beams were indicated by the formation of the cracks which occur while resisting the midpoint load (see Appendix 5).Cracks on B_{20} beams were as severe as the control beams but the evaluation of the strength of the RC beams could not be made from the cracks formation. When loads were applied to the beam, the concrete cracked due to the excess tension forces whilst the steel reinforcement was still resisting the tensile forces by the deformation of the rebar. Thus, the rebar plays an important role in resisting load in RC beam which was depending on the characteristics of the epoxy jointed steel bars.

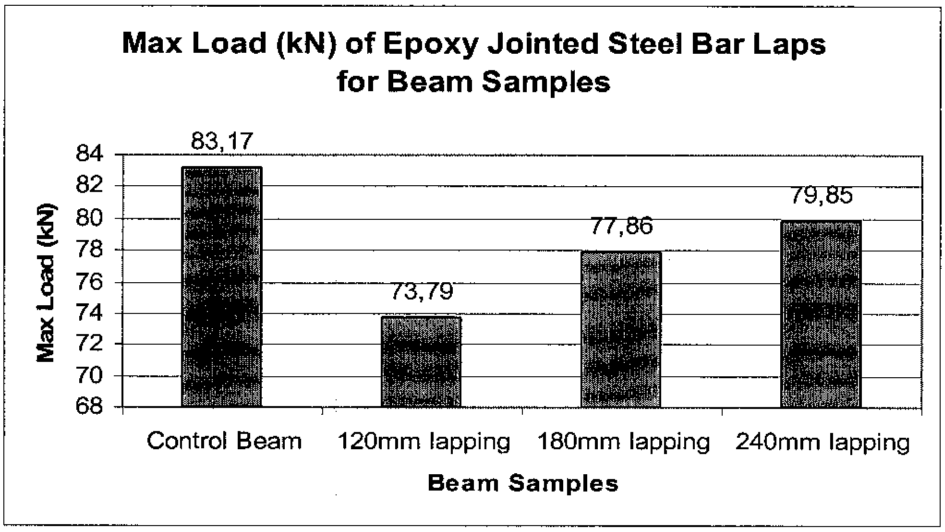


Figure 4.12: Maximum Load of Epoxy Jointed Steel Bar Lap for Beam Samples

From Figure 4.12, the percentage difference of RC beam loading for 120mm, 180mm and 240mm laps are -11.3%, 0.3% and -4% respectively from the continuous RC beam which are still under ±15% tolerances. For a positive percentage, it shows that the specified lap length has a better value compared to the continuous RC beam. The graph proved that 120mm, 180mm and 240mm steel bar lapping are identically the same as the continuous RC beam in load transferring.

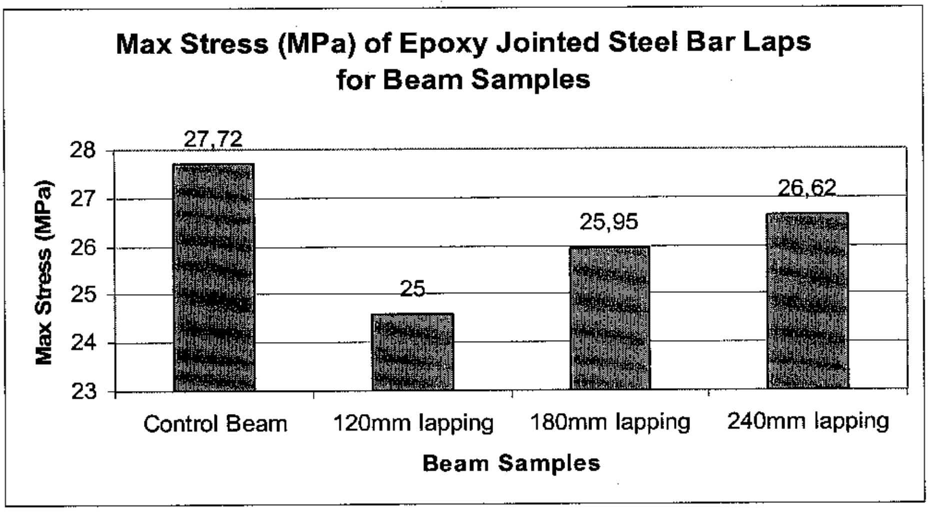


Figure 4.13: Maximum Stress of Epoxy Jointed Steel Bar Lap for Beam Samples

From Figure 4.13, the percentage difference of RC beam stress for 120mm, 180mm and 240mm are -11.3%, -6.4% and -4.1% respectively from the continuous RC beam which are still under ±15% tolerances. The graph proved that 120mm, 180mm and 240mm steel bar lapping are identically the same as the continuous RC beam in inducing the stress.

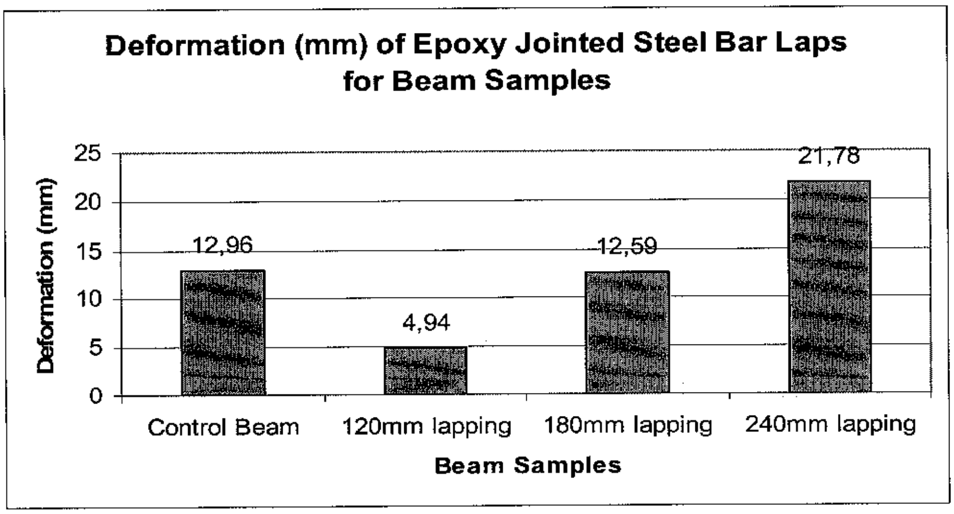


Figure 4.14: Deformation of Epoxy Jointed Steel Bar Lap for Beam Samples

From Figure 4.14, the percentage difference of RC beam deformation for 120mm, 180mm and 240mm are -61.9%, -2.9% and 68.1% respectively from the continuous RC beam which are still under ±15% tolerances. The graph proved that 180mm and

240mm steel bar lapping are identically the same as the continuous RC beam in steel bar deformation. The difference value of steel deformation was affected by the lap length and also by the binding properties of epoxy itself. Longer the lap length, bigger is the deformation.

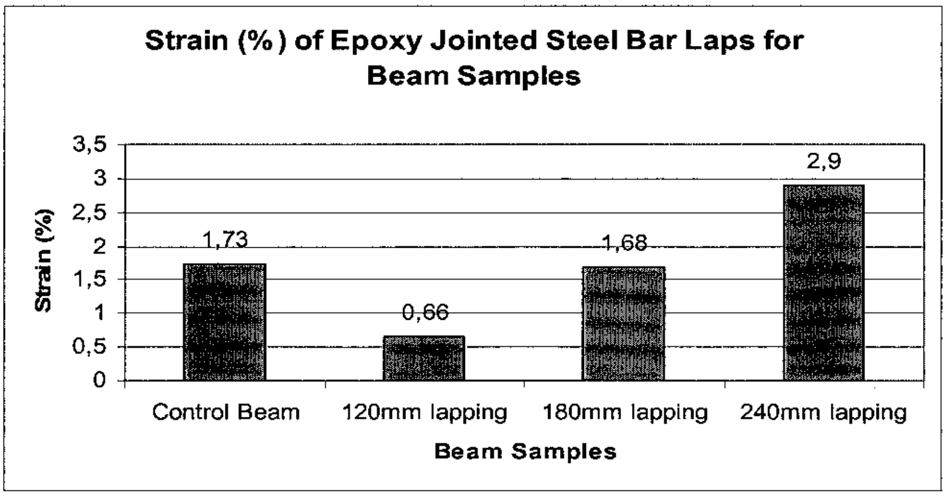


Figure 4.15: Strain of Epoxy Jointed Steel Bar Lap for Beam Samples

From Figure 4.15, the percentage difference of RC beam deformation for 120mm, 180mm and 240mm are -61.9%, -2.9% and 67.6% respectively from the continuous RC beam. The graph proved that 180mm and 240mm steel bar lapping are identically the same as the continuous RC beam in strain which are considered under ±15% tolerances.

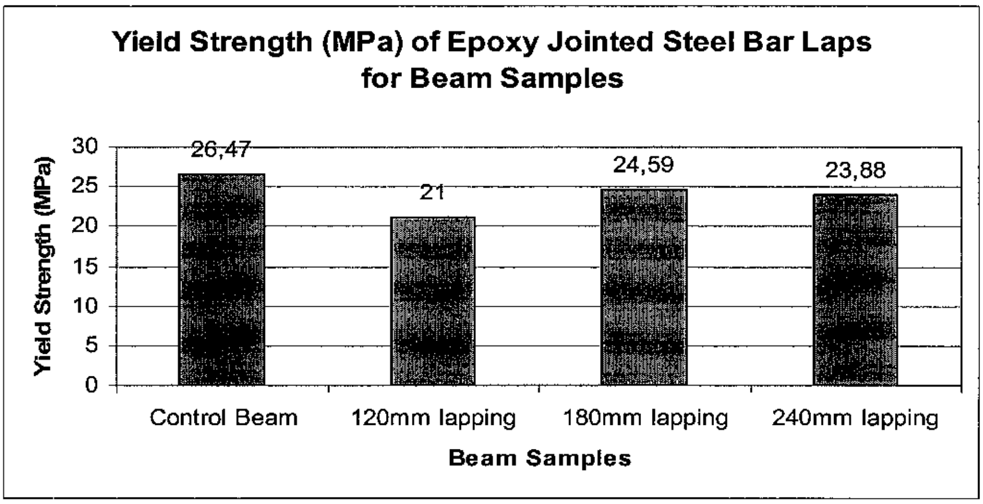


Figure 4.16: Yield Strength of Epoxy Jointed Steel Bar Lap for Beam Samples

From the Figure 4.16, the percentage difference of RC beam deformation for 120mm, 180mm and 240mm are -20.7%, -7.1% and -9.8% respectively from the continuous RC beam. The graph proved that 180mm and 240mm steel bar lapping are identically the same as the continuous RC beam in Yield Strength of the steel bar which are considered under ±15% tolerances. For a standard steel bar used, the yielding of the steel should be the same with each other. But in this case of steel lapping, the epoxy gives influenced on the yielding strength of the steels which make it differ from other beams.

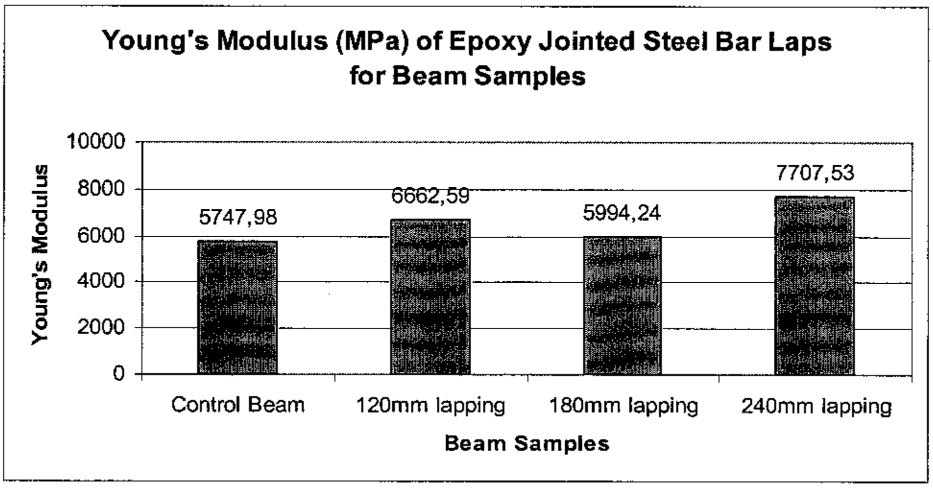


Figure 4.17: Young's Modulus of Epoxy Jointed Steel Bar Lap for Beam Samples

From Figure 4.17, the percentage difference of RC beam deformation for 120mm, 180mm and 240mm are 15.9%, 4.3% and 34.1% respectively from the continuous RC beam. The graph proved that 120mm, 180mm and 240mm steel bar lapping are identically the same as the continuous RC beam in Young's Modulus of the steel bar which are considered under ±15% tolerances.

Table 4.3: Percentage difference of epoxy jointed steel lap beams to control beam

Lap length	Percentage Difference to Control Beam (%)					
	Max Load	Max Stress	Deformation	Strain	Yield Strength	Young's Modulus
120mm	-11.3	-11.3	-61.9	-61.9	-20.7	+15.9
180mm	+0.3	-6.4	-2.9	-2.9	-7.1	+4.3
240mm	-4.0	-4.1	+68.1	+67.6	-9.8	+34.1

From Table 4.3 above, it can be concluded that 180mm is the optimum length for the epoxy jointed steel bar lap beams. 120mm lap length is not sufficient for an effective design of epoxy jointed steel bar lap due to large difference in deformation and strain. 240mm lap length could also be used instead of 180mm as longer lap lengths are able in transferring the loads.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the experimental works on this study, the pullout strength of different epoxy lap lengths and the flexural strength of RC beam were identified using the Universal Testing Machine.

Through the pullout test, all epoxy jointed laps failed due to broken of the bonding parts of the epoxy jointed lap. From the result obtained, P_{15}, 180mm lap length gave the highest load taken with the highest Rm/Re ratio. Quality of mixing and pasting of epoxy paste to the steel lap affected the load bearing of the brittle epoxy jointed lap for steel reinforcement; hence careful handling should be practiced.

Results from the flexural strength test indicated that beam of 180mm and 240mm epoxy jointed steel laps were as strong as continuous beam with a tolerance of $\pm 15\%$. Thus the optimum lap length for epoxy jointed steel bar lap is 180mm.

As the result, a successful adhesively-bonded joint, safe and economic cost effective structural design was identified. With the success of this project, epoxy jointed lap may be a good alternative in rectifying construction error due to shortened lap length and able to reduce steel scrap at construction site.

5.2 Recommendations

- With the further investigation of Sikadur-30 for lapping of steel reinforcement in RC beam on different steel sizes, a detail behavior of epoxy jointed laps could be determined.
- The epoxy jointed laps may also be tested on its behavior on the situation of fire as epoxy has low melting point.
- The epoxy jointed steel bars could be tested on the proposed design below. Three to four short steel bars could connected together with 180mm lap length and tested under static flexural strength test and other tests.

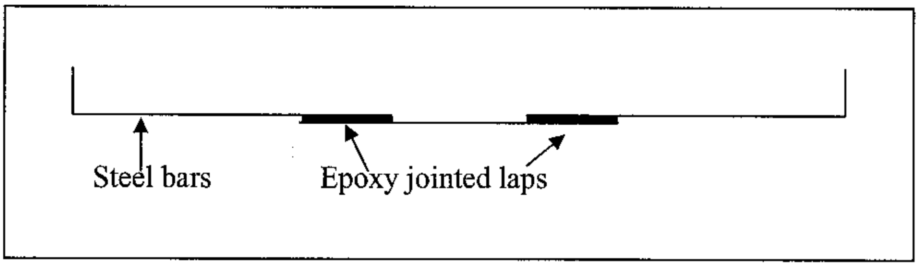


Figure 5.1: Proposed design of epoxy jointed steel bar laps

CHAPTER 6

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APPENDICES

APPENDIX 1: TABLE 3.29 BS 8110 DESIGN OF LAP LENGTH

Table 3.29 Ultimate anchorage bond lengths and lap lengths as multiples of bar size

Reinforcement type	Grade 250 plain	Grade 460			
		Plain	Deformed type 1	Deformed type 2	Fabric
	Concrete cube strength 25				
Tension anchorage and lap length	39	72	51	40	31
1.4 x tension lap	55	101	71	57	44
2.0 x tension lap	78	143	101	81	62
Compression anchorage length	32	58	41	32	25
Compression lap length	39	72	51	40	31
	Concrete cube strength 30				
Tension anchorage and lap length	36	66	46	37	29
1.4 x tension lap	50	92	64	52	40
2.0 x tension lap	71	131	92	74	57
Compression anchorage length	29	53	37	29	23
Compression lap length	36	66	46	37	29
	Concrete cube strength 35				
Tension anchorage and lap length	33	61	43	34	27
1.4 x tension lap	46	85	60	48	37
2.0 x tension lap	66	121	85	68	53
Compression anchorage length	27	49	34	27	21
Compression lap length	33	61	43	34	27
	Concrete cube strength 40				
Tension anchorage and lap length	31	57	40	32	25
1.4 x tension lap	43	80	56	45	35
2.0 x tension lap	62	113	80	64	49
Compression anchorage length	25	46	32	26	20
Compression lap length	31	57	40	32	25

NOTE. The values are rounded up to the whole number and the lengths derived from these values may differ slightly from those calculated directly for each bar or wire size.

APPENDIX 2: SIKADUR® 30 TECHNICAL DATA SHEET

Technical Data Sheet
Edition 2, 2005
Identification no.
02 04 01 04 001 0 000001
Version no. 0010
Sikadur® 30

Sikadur® 30

Adhesive for Bonding Reinforcement

Description	Solvent-free, thixotropic, epoxy-based on two-component adhesive mortar.
Use	*As an adhesive for bonding reinforcements, adhesive mortar and filler to :* ■ Concrete, stone ■ Steel ■ Epoxy *For structural bonding of :* ■ Sika CarboDur, brickwork , timber to concrete ■ Steel plates to concrete ■ Concrete elements ■ Bridge segments *Bonding of :* ■ Starter bars ■ Wall anchors ■ Fixings, etc. *For vertical and overhead filling of :* ■ Holes ■ Dimensional inaccuracies, etc
Advantages	■ Easy to mix and apply ■ No primer needed ■ Non-sag in vertical and overhead applications ■ Solvent free ■ Hardening is not affected by high humidity ■ Hardens without shrinkage ■ High creep resistance under permanent load ■ High mechanical strength ■ High abrasion and shock resistance ■ Shrinkage-free curing ■ Impermeable to liquids and water vapour ■ Components come in different colors therefore homogeneity of mix is easy to check
Test reports	- IBMB, TU Braunschweig, test report No. 1871/0054, 1994 : approval for Sikadur-30 Epoxy adhesive. - IBMB, TU Braunschweig, test report No. 1734/6434, 1995: Testing for Sikadur-41 Epoxy mortar in combination with Sikadur-30 Epoxy adhesive for bonding of steel plates.

Technical Data

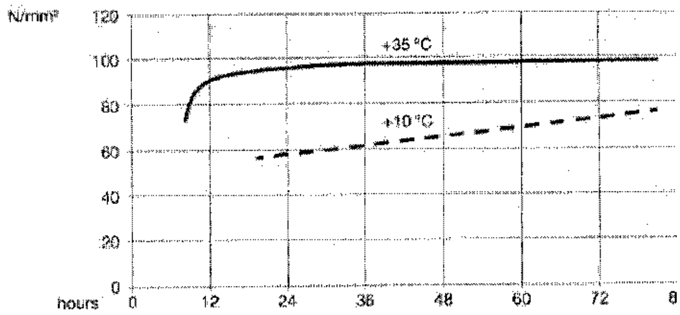
Colour	Comp. A : white Comp. B: black Comp. A+B mixed: light grey
Consistency	Comp. A+B mixed: creamy paste
Mix ratio	Comp. A: B = 3 : 1 by weight and volume
Storage	Store in dry condition at temperatures between +5°C and +30°C. Protect from direct sunlight
Shelf life	24 months from date of production if stored in original unopened packing.
Packaging	- Pre-dosed units (Comp. A+B) at 6 kg

Physical Data

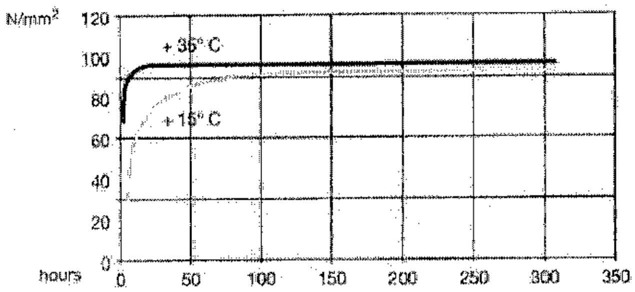
Density	~ 1.65 kg/l (mixed)
Pot life (to F.I.P.*)*	40 minutes (at +35°C) 110 minutes (at +20°C)
Open time (to F.I.P.*)*	30 minutes (at +35°C)
Layer Thickness	Max 30 mm layer thickness
Sag flow (to F.I.P.*)	3-5 mm (at +35°C) (on vertical surfaces)
Squeezability at 15 kg (to F.I.P.*)	4'000 mm^2 (at +15°C)
Shrinkage (to F.I.P.*)	0.04%
Glass transition temperature (to F.I.P.*)	62°C
Heat deflection temperature (ASTM 648)	Curing : HDT: 7d, 10°C: 36°C: 7d, 35°C: 53°C:
Modulus of elasticity static (to F.I.P.*)	12'800 N/mm^2
Compressive strength (to DIN 53455)	> 80 N/mm^2 (at 35°C)
Tensile strength (to EN 196)	> 25 N/mm^2
Shear strength (to F.I.P.*)	Concrete failure (~15 N/mm^2)
Adhesive Tensile strength on steel	>21 N/mm^2 (to sandblasted substrate to Sa 2.5)
Coefficient of thermal expansion	9 x 10^{-5} per °C (-10°C to +40°C)
Note	The figures given may vary according to the mixing intensity and the amount of air introduced.

* Fédération Internationale de la Précontrainte

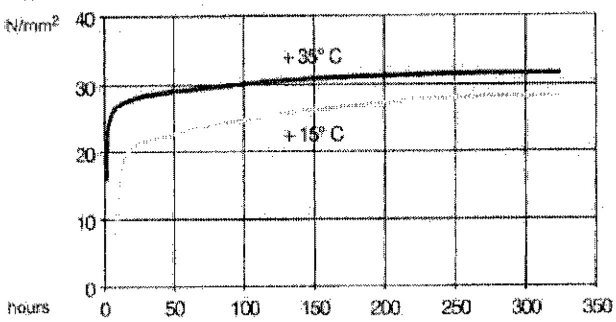
Compressive strength



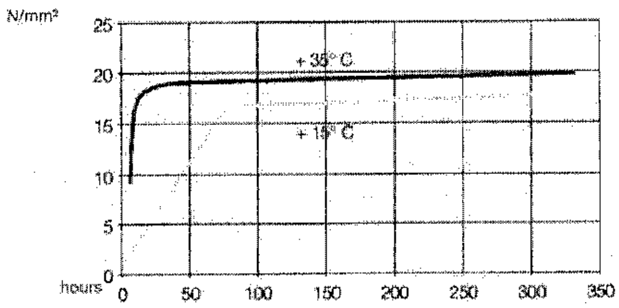
Compressive strength (to EN 196)



Tensile strength (to DIN 53455)



Shear strength (to Sika)



Application

Substrate

Concrete, stone, brickwork :

- Clean, free from and grease, dry, no loose particles or laitance.
- Concrete age, depending on climate, 3 to 6 weeks.
- Preparation : Sandblasting, high-pressure water jetting, grinding
- Max. substrate moisture : 4% pbv
  When applied to mat moisture concrete, brush Sikadur-30 well into substrate
- If the concrete surface has large uneven sections or holes after preparation, these must first be filled with Sikadur-41 or a mixture of Sikadur-30 and quartz sand Sikadur-501 (mixing ratio 1 : 1 by weight)

Timber :

- Clean, free from oil and grease
- Sandblast or grind

Structural steel 37, V2A-Steel (WN 1.4 301) :

- Free from grease and oil, free from rust, scale and rolling "skin"
- Preparation : Sandblast SA 2.5
- Beware of condensation (dew point), application only at >3°C above dew point
- If the cleaned steel is not bonded immediately, the surface must be given one coat of Sikagard-63 N or Icosit 277 to protect it from further corrosion.

Epoxy :

- Free from oil and grease
- Grind well using coarse abrasive

Mixing

Part A : part B = 3 : 1 by weight or volume

Pre-dosed packs :

Add component B to component A and stir with a mixing spindle fitted to an electric low speed mixer (max. 500 rpm) to avoid entrapping of air. Mix thoroughly for about 3 minutes to uniform appearance. Then, pour the whole mix into a clean container and

stir again for approx. 1 more minute at low speed to keep air entrapment at a minimum.

Bulk packing, not pre-dosed:

Add the components in the correct proportion using a scale. Pour them into a suitable mixing container and stir correctly using an electric low speed mixer as indicated for ready to use pre-dosed packs.

The pot life begins when the resin and hardener are mixed. It is shorter at high temperatures and longer at low temperatures. The greater the quantity mixed, the shorter the pot life. To obtain longer workability at high temperatures, the mixed adhesive may be divided into portions. Another method is to chill components A and B before mixing them.

Application	The homogeniously-mixed Sikadur-30 is applied with a spatula, trowel or float. When bonding steel plates Sikadur-30 is applied to the strips in „pitched-roof" shape. Within the open time the steel plates must be fixed in their final position. Steel plates are being fixed to the concrete substrate with the aid of specially prepared supporting scaffolding. since at normal ambient temperature sikadur-30 cures very fast, the scaffolding can be removed within 2-3 days (please refer to the curing times at various temperatures). For the application of Sika CarboDur laminates, please refer to the corresponding product data sheet. It is recommended to check the adhesive with regard to strength development by producing cubes at site and to test them for compressive and flexural strength.
Cleaning	Clean tools immediately with Colma cleaner. Wash hands and skin thoroughly in warm soap water. When uncured, Sikadur-30 components A+B, are water polllutants and should not be discharged into drains, waterways or the ground. Colma cleaner and Sikadur-30 residues must always be disposed of in accordance with the regulations. Cured material can only be removed mechanically.

Application Limitations

Temperature	Substrate and ambient: +10°C to +35°C
Material temperature	Sikadur 30 must be applied at temperature between: +5°C to +30°C
Dew point	Beware of condensation ! Ambient temperature during application must be at least 3 °C above dew point

Safety Instructions

Safety precautions	Product can cause skin irritation. Wear protective clothing (gloves, safety glasses). Cover hands with barrier cream before application. In contact with eyes or mucous membranes, rinse thoroughly with clean warm water immediately and seek medical attention without delay.
Ecology	In a liquid state material contaminates water. Do not dispose into water or soil but according to local regulations
Toxicity	Comp. A : Class 4 under the relevant Swiss Health and Safety Codes. Observe warning on packing. Comp. B : Non Toxic
Transport	Comp. A : Non hazardous Comp. B : 8/65 c)

Legal Notes

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Palu, Tel : 0451-454855 – 422122, Fax : 0451-454856
Manado, Tel /Fax : (0431) 324089

APPENDIX 3: MIX DESIGN CALCULATION

Concrete design for beams

Mix ratio	=	1 : 2.33 : 3.5
w/c ratio	=	0.55
Total ratio by weight	=	7.38

Volume of 1 beam	=	0.15m x 0.15m x 0.75m
	=	$0.016875m^3$
Adding 15% of wastage	=	0.016875 x 1.15
	=	$0.01940625\ m^3$

Materials used in weight (kg) for one beam

Cement	=	$\frac{2400}{7.38} \times 0.01940625 \times 1$
	=	6.31 kg
Sand	=	$\frac{2400}{7.38} \times 0.01940625 \times 2.33$
	=	14.70 kg
Gravel	=	$\frac{2400}{7.38} \times 0.01940625 \times 3.5$
	=	22.09 kg
Water	=	$\frac{2400}{7.38} \times 0.01940625 \times 0.55$
	=	3.47 kg

Concrete design for cubes

Volume of 1 cube	=	0.15m x 0.15m x 0.15m
	=	$0.003375\ m^3$
Adding 15% of wastage	=	0.003375 x 1.15
	=	$0.00388125\ m^3$

$$\text{Cement} = \frac{2400}{7.38} \times 0.00388125 \times 1$$

$$= 1.26\ kg$$

$$\text{Sand} = \frac{2400}{7.38} \times 0.00388125 \times 2.33$$

$$= 2.94\ kg$$

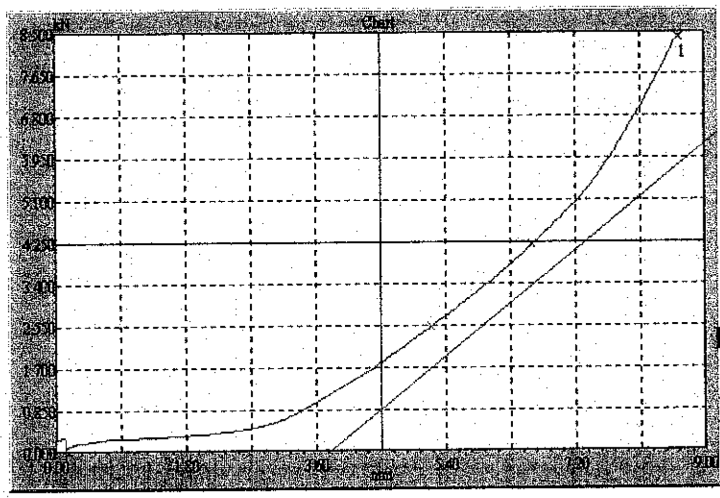
$$\text{Gravel} = \frac{2400}{7.38} \times 0.00388125 \times 3.5$$

$$= 4.42\ kg$$

$$\text{Water} = \frac{2400}{7.38} \times 0.00388125 \times 0.55$$

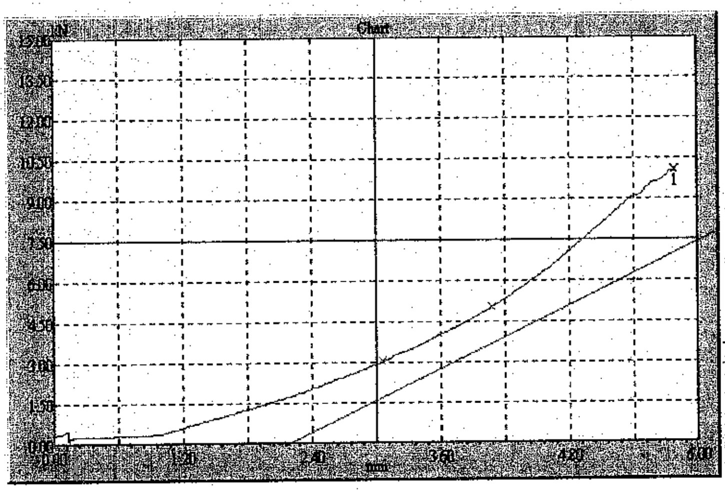
$$= 0.69\ kg$$

APPENDIX 4: PULLOT TEST RESULTS



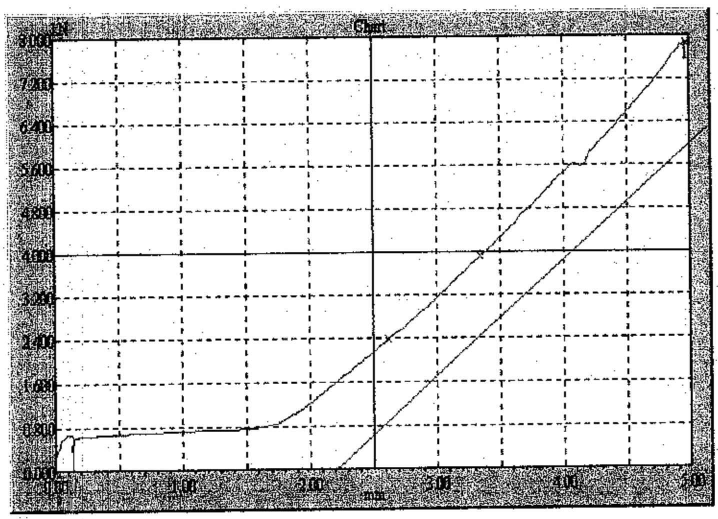
Legend
Applied load
Modulus of Elasticity

Appendix 3.1: Load(kN) versus Stroke(mm) Graph for P_{10-1}



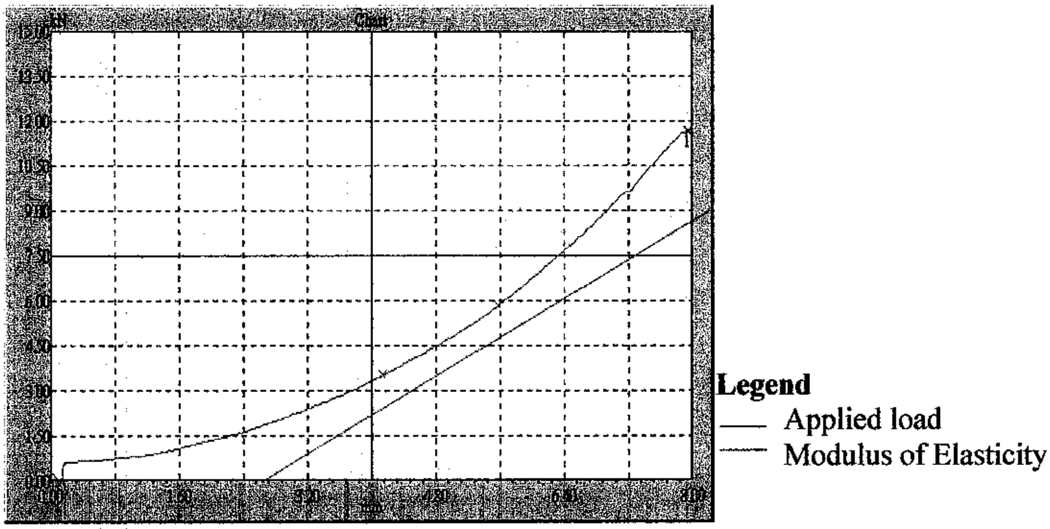
Legend
Applied load
Modulus of Elasticity

Appendix 3.2: Load(kN) versus Stroke(mm) Graph for P_{10-2}

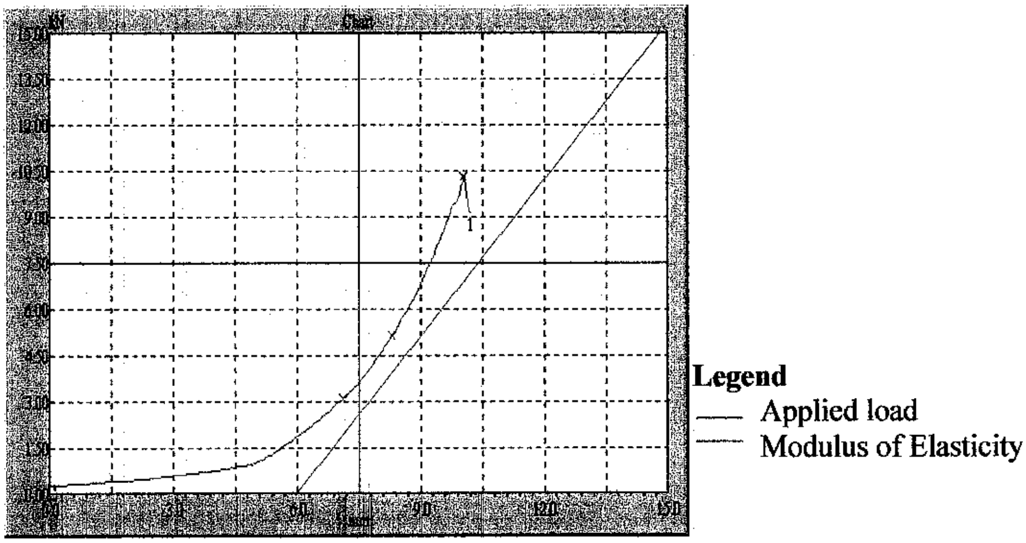


Legend
Applied load
Modulus of Elasticity

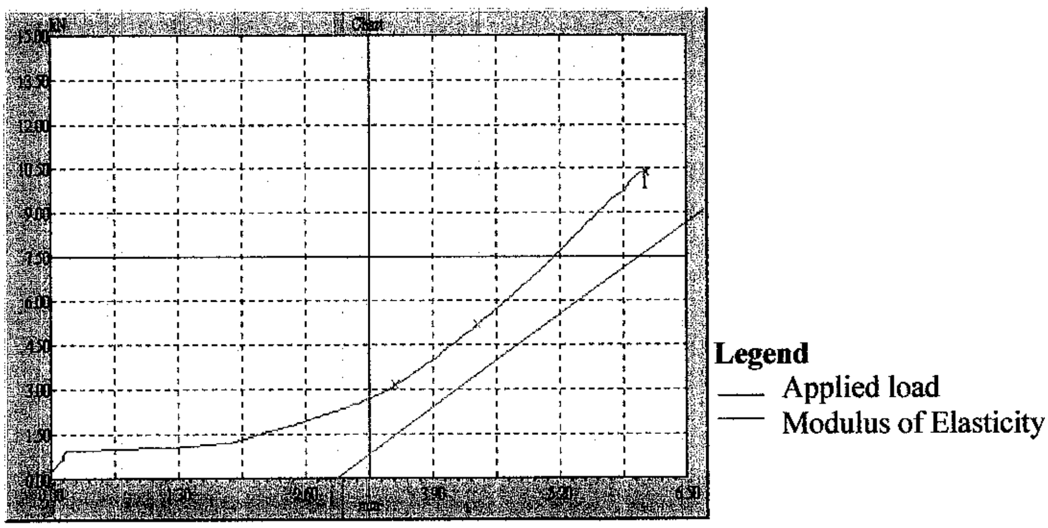
Appendix 3.3: Load(kN) versus Stroke(mm) Graph for P_{10-3}



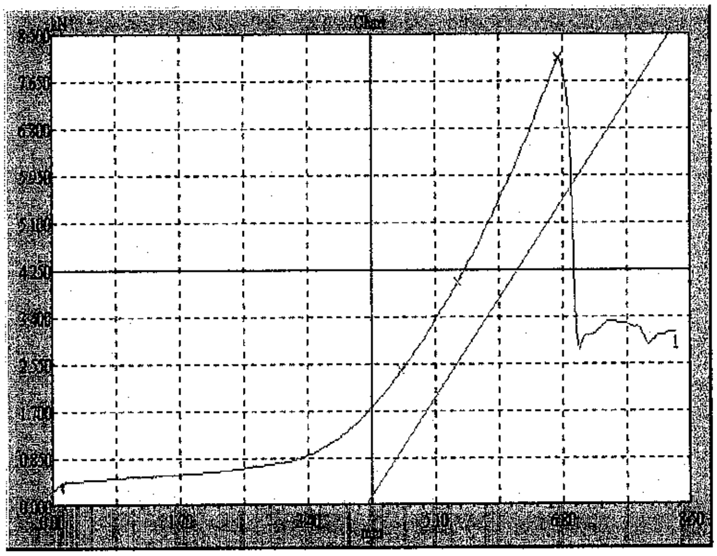
Appendix 3.4 : Load(kN) versus Stroke(mm) Graph for P_{15-1}



Appendix 3.5: Load(kN) versus Stroke(mm) Graph for P_{15-2}

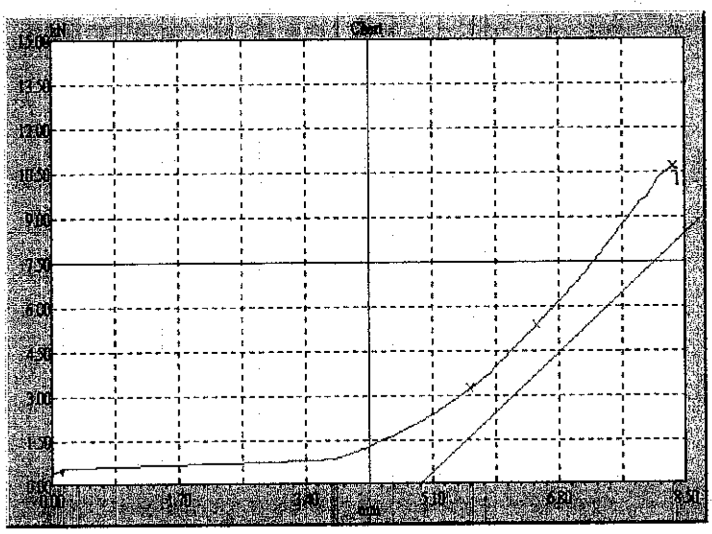


Appendix 3.6: Load(kN) versus Stroke(mm) Graph for P_{20-1}



Legend
— Applied load
— Modulus of Elasticity

Appendix 3.7: Load(kN) versus Stroke(mm) Graph for P_{20-2}



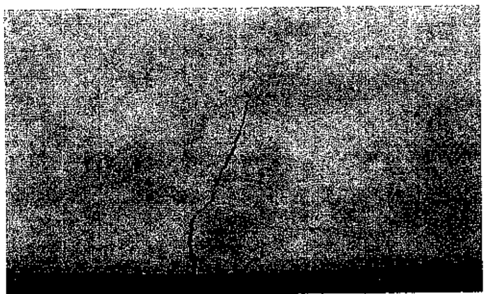
Legend
— Applied load
— Modulus of Elasticity

Appendix 3.8: Load (kN) versus Stroke(mm) Graph for P_{20-3}

APPENDIX 5: FLEXURAL STRENGTH TEST RESULTS

Failure of Beam Samples

Appendix 4.1: Side view on damage of Control Beam



Appendix 4.2: Side view on damage of B_{10}

Appendix 4.3: Side view on damage of B_{10}

Appendix 4.4: Side view on damage of B_{20}

FLEXURAL STRENGTH TEST RESULT FOR BEAMS

CONTROL BEAM

UNIVERSITI TEKNOLOGI PETRONAS

Civil Engineering Department

31750 Seri Iskandar, Tronoh, Perak Darul Ridzuan

Bending Test Report

Report No : 0001mimi2

Date : 2005-11-11

Group :

Operator :

Diameter : 150.00mm

Guage length : 750.00mm

Max. Load : 74.20kN

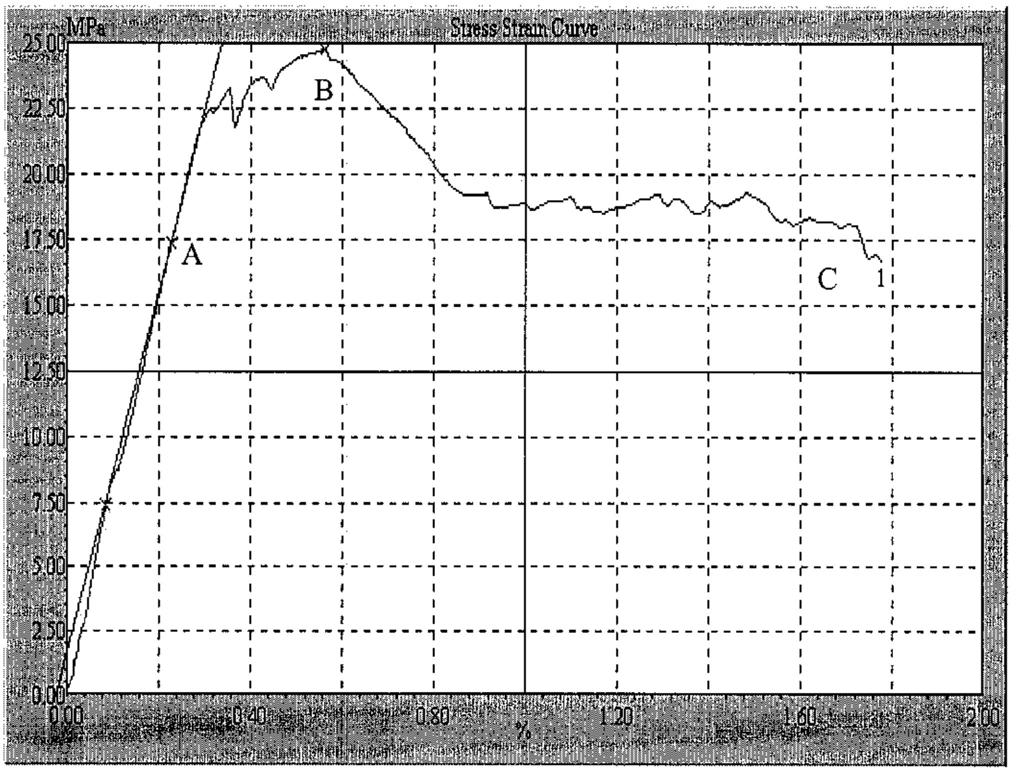
Max stress : 24.73MPa

Deformation at break : 13.35mm

Strain at break : 1.78%

Yield Strength : 24.66MPa

Young's Modulus : 5786.21MPa



Appendix 4.6: Flexural Strength Result of Control Beam

120mm LAPPING

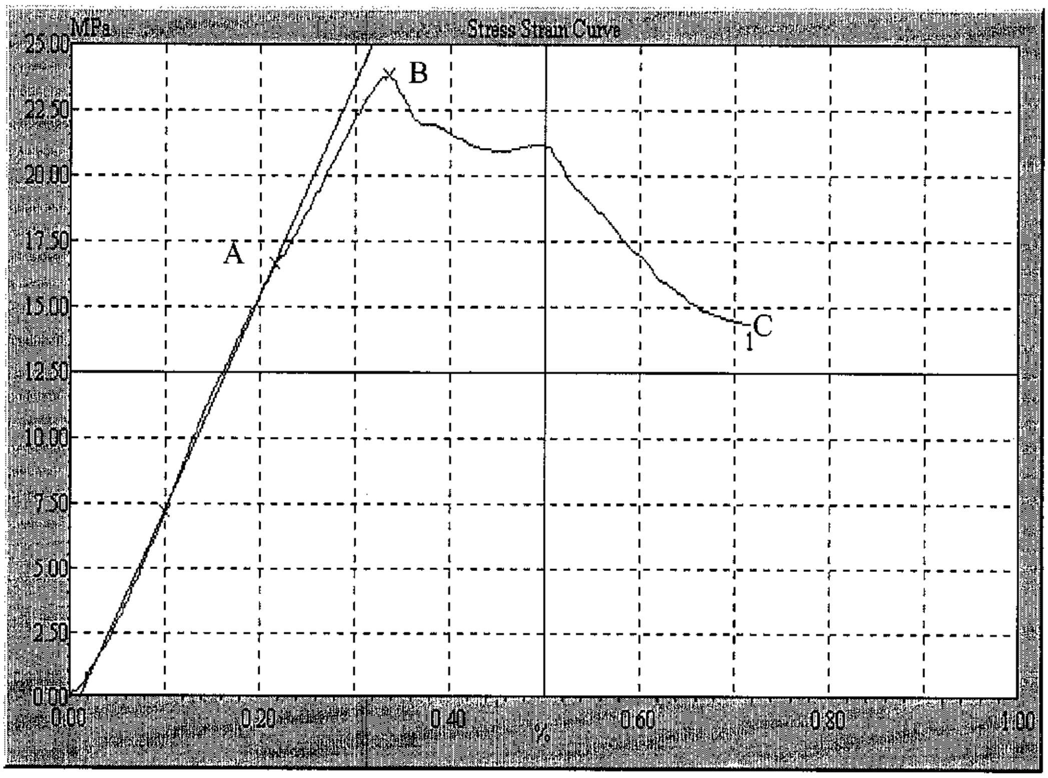
UNIVERSITI TEKNOLOGI PETRONAS

Civil Engineering Department

31750 Seri Iskandar, Tronoh, Perak Darul Ridzuan

Bending Test Report

Report No : 0001mimi4	Max. Load : 71.26kN
Date : 2005-11-11	Max stress : 23.75MPa
Group :	Deformation at break : 5.39mm
Operator :	Strain at break : 0.72%
Diameter : 150.00mm	Yield Strength : 20.89MPa
Guage length : 750.00mm	Young's Modulus : 6755.29MPa



Appendix 4.8: Flexural Strength Result of B_{10}

180mm LAPPING

UNIVERSITI TEKNOLOGI PETRONAS

Civil Engineering Department

31750 Seri Iskandar, Tronoh, Perak Darul Ridzuan

Bending Test Report

Report No : 00012

Date : 2006-03-22

Group :

Operator :

Diameter : 150.00mm

Guage length : 750.00mm

Max. Load : 77.86kN

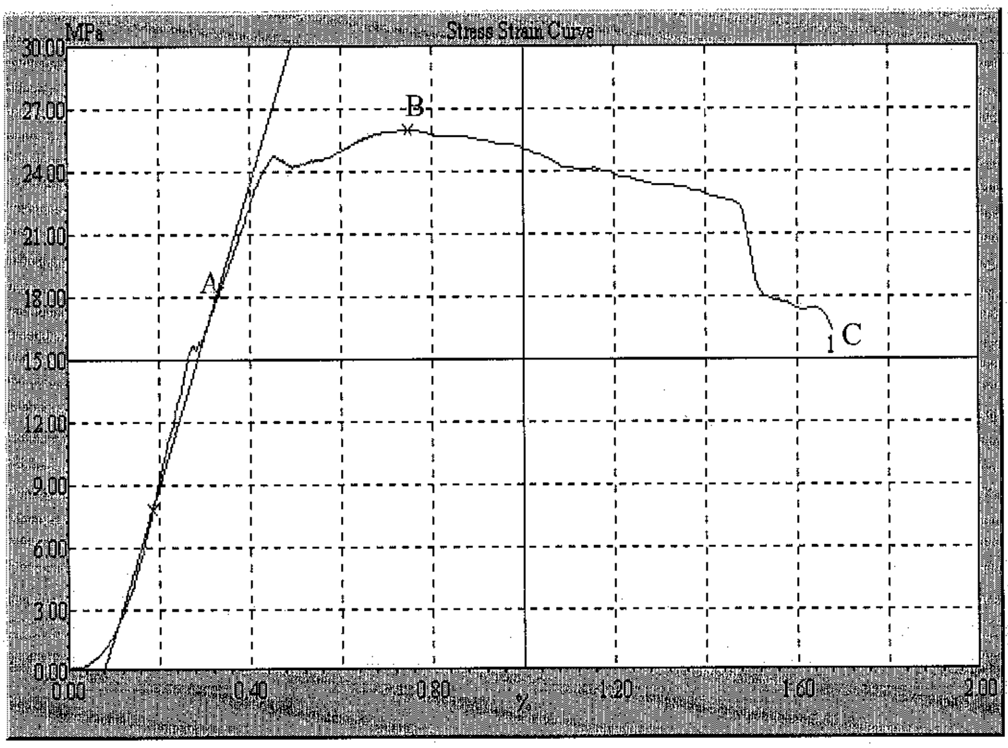
Max stress : 25.95MPa

Deformation at break : 12.59mm

Strain at break : 1.68%

Yield Strength : 24.59MPa

Young's Modulus : 5994.24MPa



Appendix 4.9 : Flexural Strength Result of B_{15}

240mm LAPPING

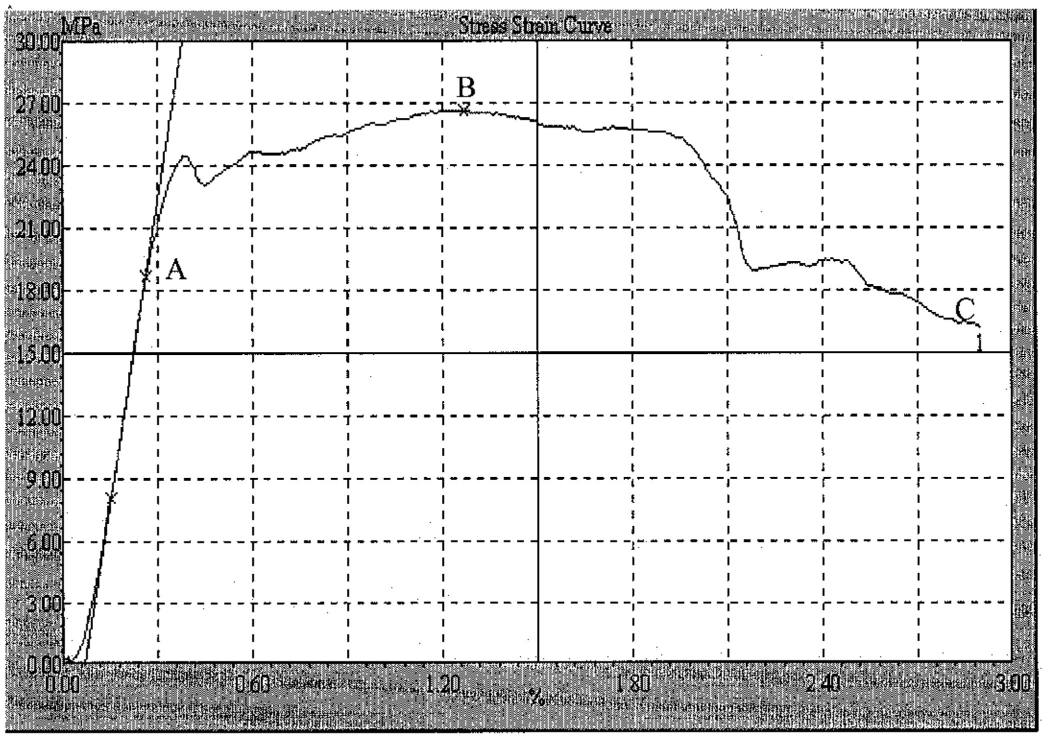
UNIVERSITI TEKNOLOGI PETRONAS

Civil Engineering Department

31750 Seri Iskandar, Tronoh, Perak Darul Ridzuan

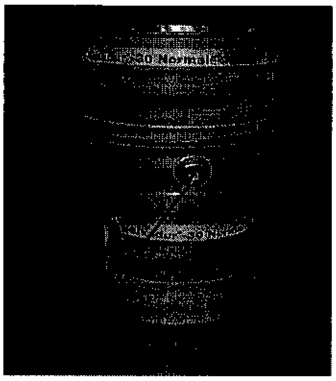
Bending Test Report

Report No : 00011	Max. Load : 79.85kN
Date : 2006-03-22	Max stress : 26.62MPa
Group :	Deformation at break : 21.78mm
Operator :	Strain at break : 2.90%
Diameter : 150.00mm	Yield Strength : 23.88MPa
Guage length : 750.00mm	Young's Modulus : 7707.53MPa



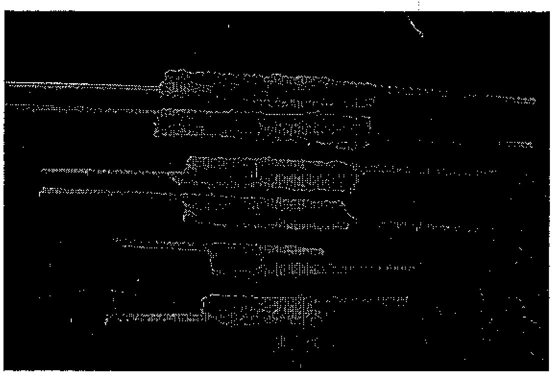
Appendix 4.11: Flexural Strength Result of B_{20}

APPENDIX 6: PHOTO GALLERY

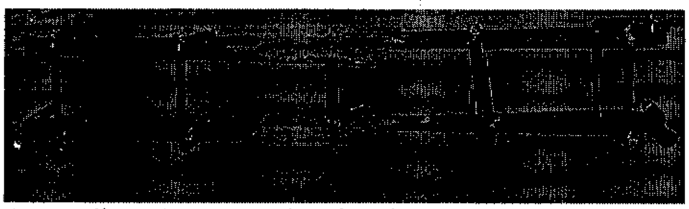


Appendix 5.1: Epoxy-Sikadur-30 used for the jointed lap

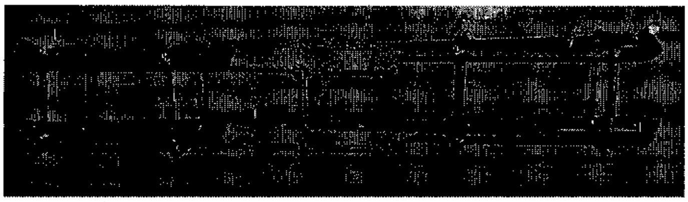
Appendix 5.2: Pasting epoxy to the jointed lap

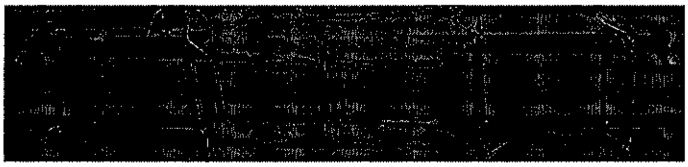


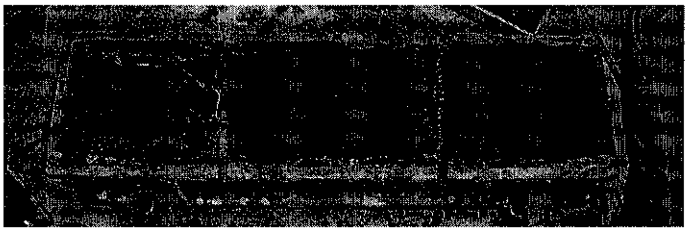
Appendix 5.3: Pullout samples of 120mm lap, 180mm lap and 240mm lap

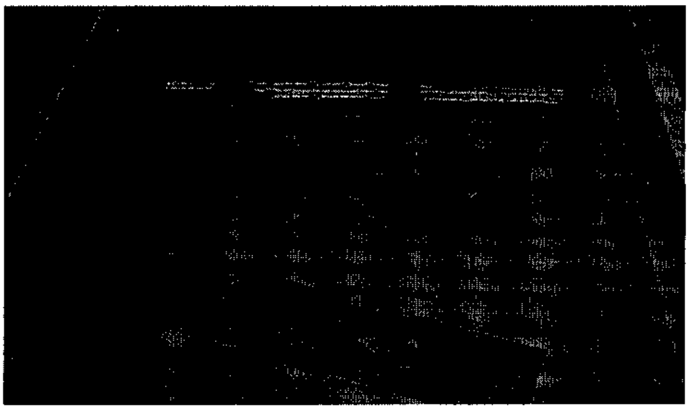


Appendix 5.4: 120mm lapping for test beams


Appendix 5.5: 180mm lapping for test beams


Appendix 5.6: 240mm lapping for test beams


Appendix 5.7: Beam casting


Appendix 5.8: Curing of beams