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Ferrocement-Timber Composite Beams Loading capacity

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Abstract. This paper presents an experimental study of simply supported ferrocement timber composite members. An adherently bound link is investigated. As a shear connector layer, an appropriate length for this type of composite beam was chosen to study the effect of shear strength on the impact of one point load (1.2 m). Sikadur 31 thixotropic epoxy resin adhesive is used. The research's primary goal is to collect data and provide information on the structural behavior of proposed ferrocement timber composite (FTC) beams. The thickness and width of timber beams, the presence and absence of a bonding layer on the shear connector, and the influence of sagging and hogging bending moments were also investigated. FTC beams are a relatively new civil engineering solution, and their behavior should be investigated to develop relevant methods for calculating their resistance. Two push-out tests were used to tentatively resolve the connector's slip and pinnacle load limits. The stiffness and strength of the connection utilized to bind a ferrocement slab to a timber beam were investigated by the authors. These criteria are critical for composite beam planning because the solidity and quality of a composite beam framework's connections determine its performance. A three-point loading test was performed on the composite beam specimens. Measurements also demonstrate that the connection is near-perfect because the slide is minimal during the test (except at failure). Converting from sagging to It has been witnessed that converting from sagging to hogging bending reduces the ultimate load by up to 24%. The suggested beams' loading It has been witnessed that Converting from sagging to hogging bending reduces the ultimate load by up to 24%.shown to be excellent when compared to their weight in tests. Epoxy resin (Sikadur 31) can be used to provide adequate bonding between the components. The highest gain in the loading capacity was 48% when the timber thickness was increased from 90 to 190 mm.

Keywords: ferrocement; timber; composite beam; Epoxy; Push out; sagging; hugging.

1. Introduction

Civil engineering construction uses a wide range of building materials. Mechanical qualities, durability, availability, workability, and other considerations may have an impact on material selection. As a result of the imposed loads, the materials respond in a variety of ways. In general, no material exists that can suit all structural requirements. As a result, engineers are attempting to arrange the various elements in a precise manner to achieve the optimal geometry by placing the components in regions that have their unique qualities (e.g., concrete in compression and steel in tension). That is the primary rationale for combining many components of different materials to maximize the value of their properties in a structural member that only uses desirable material properties. The ability to join composite components together determines the structural performance of the composite member. In general, composite constructions have better load and rigidity than non-composite counterparts, resulting in a reduction in the overall depth of composite sections. Steel and concrete are the most frequently utilized materials in civil engineering applications [1]. On the other hand, timber long been utilized for structural purposes in civil engineering applications and is considered a competitor to other traditional construction materials due to its lightweight, high strength, and sustainability [2 and 3]. In the structural field, combined timber and concrete is a well-known type. On the subject of timber-concrete, numerous experimental and numerical research has been carried out [4,5,6,7,8, and 9].To build composite parts, timber has recently been blended with other materials like glass [10,11,12,13] and steel [14,15,16,17,18,19,20,21]. Researchers have also presented timber-timber composite components to obtain novel light weight composite members [22 and 23]. In comparison to ordinary concrete, Ferrocement considers a thinned concrete element (i.e., 50 mm maximum thickness) to have a high tensile strength-to-weight ratio and superior cracking behavior. It's employed in a wide range of civil engineering projects [24]. The researchers wanted to conduct their investigation using readily available and useful concepts from technology and other areas of life. The authors discussed the appropriate qualities of lumber and ferrocement, the appropriate qualities of timber and ferrocement, as well as the benefits of composite action. As a result, the primary goal of this research is to gather data and provide information on the structural shear performance of a new proposed member made of ferrocement and timber. The bending moment region, hogging, and sagging are also investigated to see how this variable affects the behavior of a timber ferrocement composite beam. Furthermore, using of use of a push-out test to investigate the strength and performance of the epoxy adhesive employed in this study..

2.1. Experimental program

Throughout the experiment, all specimens were made with identical materials (cement, sand, water, wire mesh, epoxy, and wood). The following are the specifications of these materials: Rad-wood is one of the types of timber used in buildings, and it is known for its hardness, durability, and strength. The tests were carried out in line with ASTM – D 198 – 84 [27] for used wood. Table 1 shows the geometrical details. Table 2 displays the results of the physical and mechanical properties of timber. Figure 1 depicts the test setup for timber samples. steel wire mesh that was readily available was used. The square hole Square hole wire mesh wire diameter of the wire mesh were (0.8 and 12) mm, respectively. The mechanical properties of wire mesh were evaluated by testing three coupons of wire from a mesh roll under direct tension, as shown in Figure 2, following ACI Committee 549[28]. The tested wire mesh coupons had an average tensile strength, ultimate strength, and Young's modulus of 325 MPa, 480 MPa, and 200 GPa, respectively. Table 3 summarizes the material parameters determined for utilized steel wire mesh. Figure 3 shows the Stress-strain relationship for wire mesh.

Sikadur-31 super hydrophobic epoxy resin adhesive was used, which would be a two-component epoxy resin and hardener that is solvent-free and thixotropic (A and B). The two aspects (A and B) are mixed in a weight ratio (1:2) with a mixing paddle coupled to a sluggish electric drill, as directed by the manufacturer. Mix thoroughly until the material has a smooth consistency and is even grey The used epoxy (Sikadur 31) had flexible, compressive, and elastic modulus of 37 MPa, 42 MPa, and 43 GPa, respectively. In this study, regular Portland cement and natural sand passing through a sieve of 2.36 mm were dependent on the cement mortar. The cement-to-sand and cement-to-water ratios were 0.5 and 0.325, respectively. The drinking water was used in the mix and processing experiments. The average compressive strength of mortar after 28 days was 60 MPa.

All of the specimens were cast at the same time and kept in the same environment. The clear length of the ferrocement-timber composite (FTC) beams which tested was 1200 mm There were four different cross-sections of wood used: (85×85) mm, (85×135) mm, (85×190) mm, and (190×190) mm. The ferrocement panel had a depth of 50 mm and a breadth of 400 mm.

2.2. The Connection Between Timber and Ferrocement

Ferrocement-timber composite beam behavior is heavily influenced by the rigidity and strength of the bonding between the two components that format the compound element. Block connectors, welded studs, screws, welded bars, strips, composite dowels, bonded joints, notched joints, dowel type fasteners, screws, nail plates, and continuous mesh are all as samples of used for this purpose [25]. It is possible to use nails or screws in this scenario (FTC) beam, but this approach may generate a specific difficulty in the connection between ferrocement and timber, resulting due to galvanic corrosion. It's also worth considering strong adhesives as a linking substance [26]. A composite beam can be prepared by using a lot of connectors of the solid cross the solid cross-section of the timber beam**.** Combining timber and ferrocement to make composite structures is a cost-effective technique to create high-performance bending components, such as each material is subjected to stresses that are appropriate for its properties (timber is under tension and ferrocement is sustained compression). As a result, lightweight composite beams with high global bending stiffness and load capacity are obtained. The majority of point-shaped joints, such as screws or nails, are used, resulting in a flexible bond. To counteract this disadvantage, adhesives can be used to create a firm bond between the two materials. Epoxy as a bonding agent allows for a wide range of pre- and post-treatment options. Characteristics that make it suitable for linking diverse types.

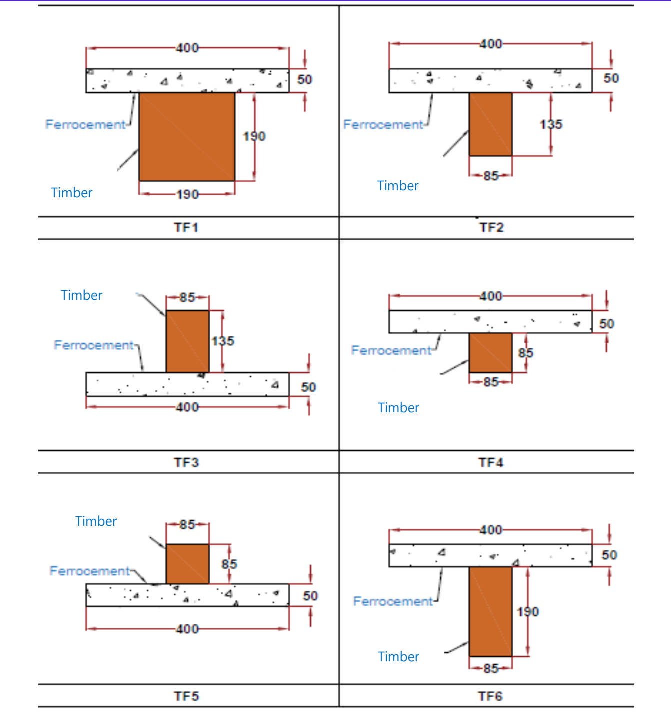

Fig. 1 shape and dimension of composite Beam

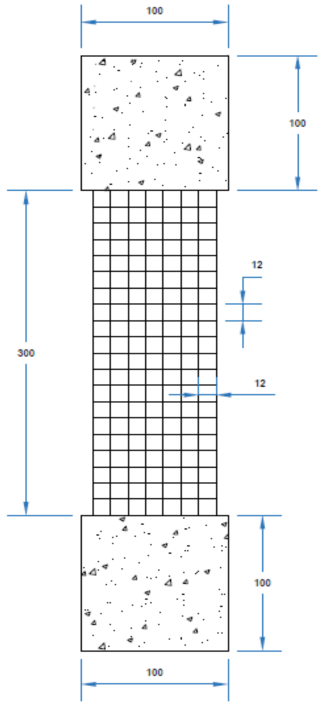

Fig. 2 shape and dimension of direct tension of wire mesh

Table 1. Details of specimens

Sample	Timber beam		Ferrocement slab			Length (mm)	curve
	Depth (mm)	Width (mm)	Width (mm)	Depth (mm)	Layer of mash		
TF1	190	190	400	50	5	1200	sagging
TF2	135	85	400	50	5	1200	sagging
TF3	135	85	400	50	5	1200	hugging
TF4	85	85	400	50	5	1200	sagging
TF5	85	85	400	50	5	1200	hugging
TF6	190	85	400	50	5	1200	sagging

Table 2. The results of physical and mechanical properties of timber

Property	Moisture content %	Specific gravity	Compression perpendicular to grains (tangential)	Compression perpendicular to grains (radial)	Compression parallel to grains	Modulus of elasticity	Flexural strength
results	3.27	0.67	8.6 MPa	12.66 MPa	40.6 MPa	19788 MPa	69 MPa

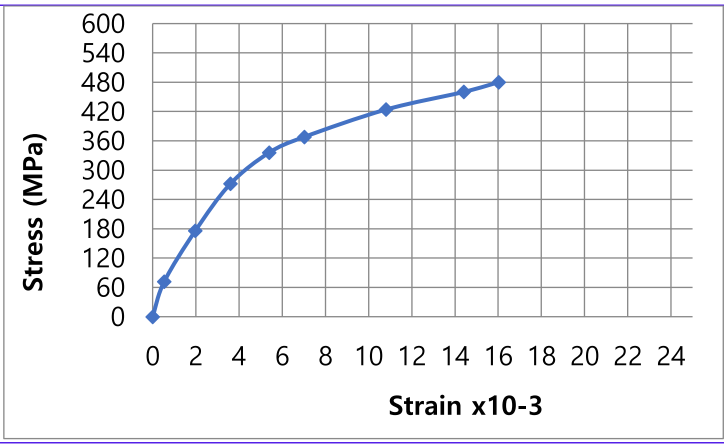

Fig.3 Stress-strain relationship for wire mesh

2.3 Fabrication

Plywood board molds with a nominal thickness of 12 mm were used to cast precast ferrocement panels. Sets of holes define the position of the mesh layers on the long sides of the molds. The five layers of steel mesh were connected with extremely fine steel wires and secured to the mold through these holes. After 30 days of curing, all specimens were tested. Furthermore, timber members were produced and cut to the specified proportions. The sides of the timber members and the ferrocement panel where they were attached had been thoroughly cleaned. After that, using epoxy adhesive, the two components of the composite beam, the timber beam and the ferrocement panel, were connected. The epoxy layer was approximately three millimeters thick. The two components were then pushed for three days with a mechanical pressed made specifically for this purpose. Figure 4 depicts the casting of ferrocement members and the assembly of ferrocement with timber.

Fig.4 Configure of Specimens

2.4. Push out test

The Push out tests should be used to evaluate the connection between the ferrocement panel and the wood beam. Push out test for adhesive bonding ferrocement-timber composite (FTC) members is not covered by any rules or specifications. As a result, the model given in this study was based on British steel-concrete composite beam specifications [30]. Push out test samples were prepared in two ways for this purpose. The prepared push out sample in the first model comprises of two ferrocement segments with dimensions of (400×300×50) mm and one wood segment with dimensions of (400×135×85) mm (PUSH1). In the second type, it is made up of two timber segments and one ferrocement segment with identical proportions to the first sample (PUSH2). The size and types of push out tests are depicted in Figures 5 and 6. As previously stated, the composite samples were glued with 3 mm of epoxy adhesive and pressed with a mechanical clip for three days and then ferrocement painted before being examined. The specimen was loaded in steady increments up to the ultimate load, with the slip between the wood and ferrocement segments being measured at each load level. The dial gages were used to measure the slip at the ferrocement/timber contact. Fig. 7 summarizes the details and findings of the tested push-out specimens. The same failure mechanisms were observed for both cases. A thin layer of mortar separated from the ferrocement segment in the first failure mode of PUSH1 and remained attached to the timber section in the interface region. The second mode of PUSH2 failure, on the other hand. This indicates that there was no deboning between the two components (ferrocement and timber) and that the adhesive epoxy layer provided a sufficient bond. As a result, the Sikadur 31 relationship might be termed flawless. Failure of push-out specimens and load–slip relationships for push out tests are depicted in Figures 7.

Fig. 6 Push out PUSH 1

Fig. 5 Push out PUSH 2

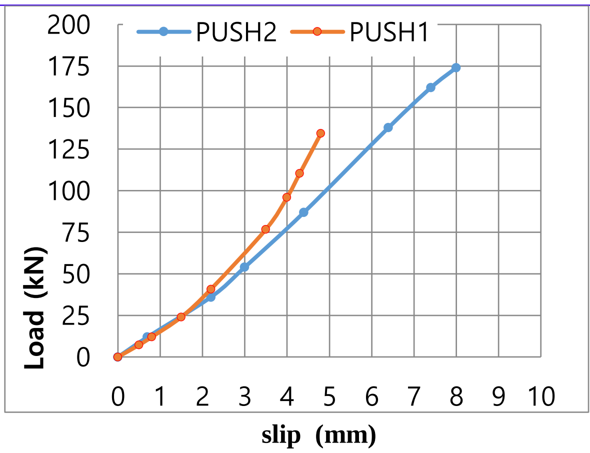

Fig. 7 Load–slip relationships for push out tests

2.5. Test set-up

All composite beam specimens have been prepared one day before the test. Timber beams were one example, while ferrocement penal was another. The point load on the beams was applied in gradual incremental steps. As the load approaches the ultimate load, these steps become smaller. The load was applied using a TORSEE universal testing machine with a capacity of 600 kN. The load was applied at the midpoint of the beam span.

3. Results and Discussion

3.1. Failure Modes

Throughout the static testing of the composite beams, many types of failure are detected. These modes were determined by two key factors: the specimen length and the type of applied bending (sagging or hogging). Fissures in the timber at the mid span tension zone failed the composite beam specimens exposed to sagging bending force (the ferrocement is at the top, and the timber is at the bottom). So that, fractures appear in the timber, almost like a little incision in the center of the strain zone, which grows upward at an angle with increasing force. The crack in the ferrocement and timber will be visible, and minor cracks will appear in the epoxy bonding region. The failure shear appear in the middle part of the structure. However, began on the bottom surface of the timber beam at the mid span and proceeded upward at an angle between 35º to 47º with the horizontal as illustrated in Figure 8. Table 3 the experimental results of tested composite beams. Figure (8 to 10) shows the composite beam after failure.

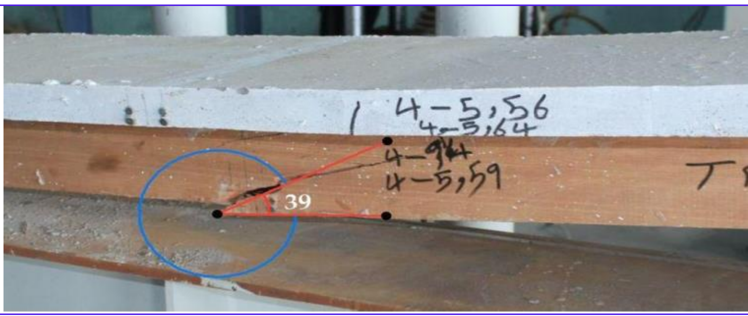

Fig. 8 specimen TF2 after failure

Table 3. Experimental results of tested composite Beams

Beams designation	Ultimate load (kN)	Ultimate moment (kN.m)	Mid-span deflection at ultimate load (mm)	Service Load (kN)
TF1	500	132.5	4.8	333.3
TF2	84	22.26	12	56.0
TF3	65	17.22	13	43.3
TF4	68.5	18.15	6.5	45.6
TF5	52	13.78	17	34.6
TF6	190	50.35	8.5	126.6

3.1.1. Behavior of Beams Under Sagging Bending

Load midspan deflection relationship for composite beams with varying timber beam depths is shown in Figure (13) for composite beams with 1.2 m length (TF6 and TF2). The explored deflection value at the ultimate load falls from 12 mm to 8.5 mm with a reduction ratio of 30% when the depth of the timber beam minimizes from 190 mm for TF6 to 135 mm for TF2, and the ultimate load decreases from 190 kN to 84 kN with a reduction ratio of 55.8%.

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Load midspan deflection relationship for composite beams with timber beam widths are shown in Figure (14). As the width increase from 90 mm for beam TF6 to 190 mm for beam TF1. The extrapolated deflection value at ultimate load increase from 4.8 mm to 8.5 mm with increase ratio of 43.5% for 1200 mm composite beam length. And the load is increase from 190kN to 500kN

3.1.2. Behavior of Beams Under Hogging Bending

Load midspan deflection relationships for composite beams (TF4) and (TF5) under sagging and hogging bending moments, respectively, are shown in Figure (15). The specimens have the same length 1200 mm and the same timber section (90 × 90) mm and ferrocement slab (400 × 50) mm. With a reduction ratio of 61.7 percent, the deflection in sagging bending is (6.5 mm) and in hogging bending is (17 mm). With a reduction ratio of 25%, the ultimate load drops from 68.5 kN for TF4 to 52 kN for TF5.
Load midspan deflection relationships for composite beams (TF2) and (TF3) under sagging and hogging bending moments, respectively, are shown in Figure (16). The specimens have the same length 1200 mm and have the same dimensions of timber section (135 × ٨٥) mm and ferrocement slab (400 × 50) mm. Sagging bending causes a deflection of (12 mm) and hogging bending causes a deflection of (13 mm) while a reduction in an ultimate 23% from 84 kN for TF2 to 65 kN for TF3. When converting from sagging to hogging bending, we've witnessed a reduction in ultimate load of up to 24%. There is also a rise in deflection. In the first scenario (sagging bending), the findings are attributable to ferrocement at the top and timber at the bottom; ferrocement has a strong compressive strength, While timber has excellent tensile strength as well as excellent compressive strength In the second scenario (hogging bending), the timber is up and the ferrocement is down, resulting in tensile strains on the ferrocement and compressive stresses on the timber.

Fig. 9 specimen TF3 after failure

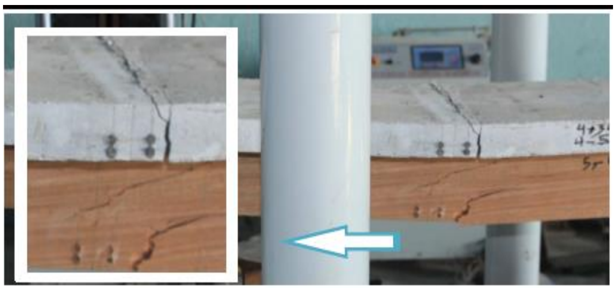

Fig. 10 specimen TF6 after failure

Fig. 11 specimenTF1 before failure

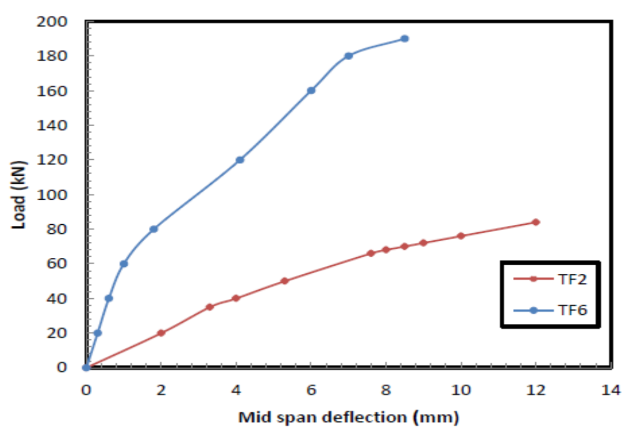

Fig. 13 Variation of midspan deflection with load for composite beams The variable is timber depth

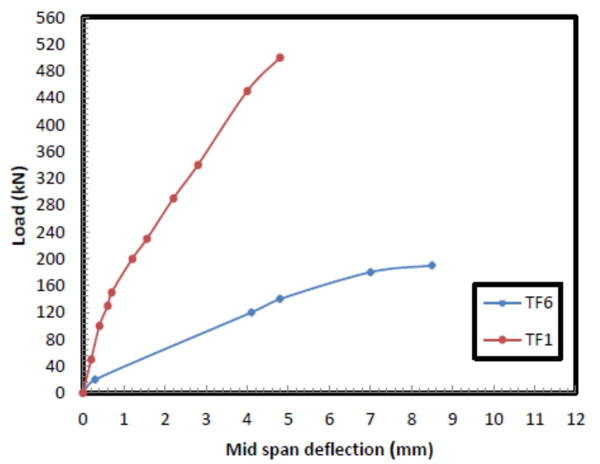

Fig. 14 Variation of midspan deflection with load for composite beams The variable is timber width

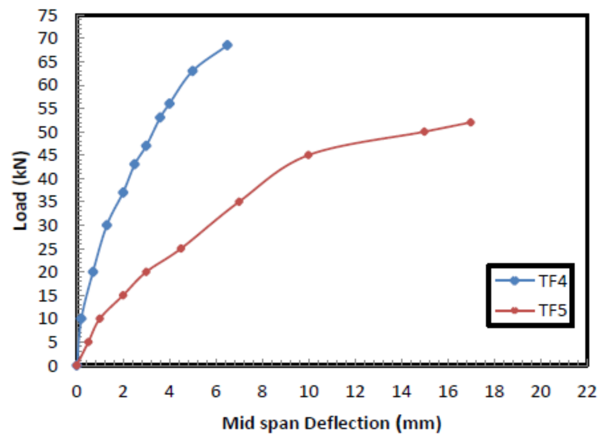

Fig. 15 Variation of midspan deflection with load for composite beams sag moment and hog moment with dimension of timber (85×85)

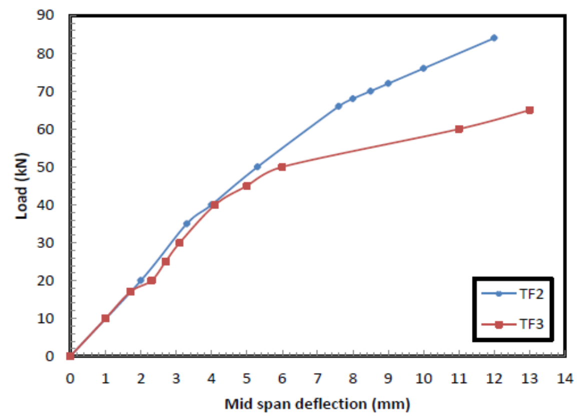

Fig. 16 Variation of midspan deflection with load for composite beams sag moment and hog mo ment with dimension of timber (135×85)

4. Conclusions

The following are the key conclusions drawn from the test findings and examination:

4.1 Push-Out Test Specimens

- The specified dimensions and qualities for push-out tests for connectors in ferrocement-timber composite beams may be regarded as the standard test for connectors.
- The load-slip relationship for an adhesive epoxy layer may be described by an exponential equation, which differs from the connection proposed for steel-concrete composite beams.
- There were two types of specimen failure. In the first, the timber beam developed a longitudinal crack that propagated throughout the length of the beam. A failure in the binding area also causes the separation of one of the ferrocement slabs, with some ferrocement connected to the epoxy surviving.
- In the case of PUSH1, one or both side slabs are detached from the wood beam when the load approaches the ultimate load.

- It's clear that employing Sikadur 31 as an adhesive epoxy layer creates a strong link between the two materials. The connection might potentially be regarded as strong, according to measurements.

4.2 Ferrocement - Timber Composite Beams

- The crushing of ferrocement in the compression zone is characteristic of beams under sagging bending moment. collapse, then spreads to the mid-span of the timber beam, with no sign of the adhesive epoxy coating being destroyed.
- In beams subjected to hogging bending forces, the failure was characterized by a crack in the tension zone of the ferrocement slab, followed by a crushing fault in the wood beam that began at the mid-span bottom surface and proceeded upward at a 40° angle with the horizontal.
- As the depth of the timber maximize, the strength and deflection dim the strength increases and deflection decreases. The crushing of ferrocement in the compression zone is characteristic of beams under sagging bending moment. The breaking then spreads to the mid-span of the timber beam, with no sign of the adhesive epoxy coating being destroyed.
In beams subjected to hogging bending forces, the failure was characterized by a crack in the tension zone of the ferrocement slab, followed by a crack fault in the wood beam that began at the mid-span
- upward surface and proceeded upward at a 40° angle with the horizontal. As the depth of the timber grows, the strength increases and deflection decreases.

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