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Experimental investigations of the structural behaviour of simply support ferrocement-timber composite beams

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Abstract. An experimental study of simply supported ferrocement timber composite members is presented in this paper. An adhesively bonded connection is examined. Sikadur 31 thixotropic epoxy resin adhesive is used as a shear connector layer. The main purpose of the research is generating data and providing information about the structural behaviour of proposed ferrocement timber composite (FTC) beams. Several parameters studied including thickness, and width of timber beams, the number of wire mash layers of ferrocement slab and the presence and absence of a bonding layer of the shear connector and the effect of sag and hog bending moment. Ferrocement-timber composite (FTC) beams are a relatively new civil engineering solution and their behaviour should be investigated to develop relevant methods for calculating their resistance. The slip and the pinnacle load limit for connector were resolved tentatively in two push-out tests. The authors examined the stiffness and the strength of the connection used to join a ferrocement slab with a timber beam. These parameters are fundamental for planning composite beam, on the grounds that the conduct of a composite beam framework is relied upon the solidness and the quality of its associations. The composite beams specimens were subjected to a three-point loading test. Measurements also show that the connection could be considered perfect as the slip remains very little during the test (except at failure). Tests disclosed excellent loading capacity of the suggested beams relative to their weight. The use of epoxy resin can be providing appropriate bonding between the two layers. The energy absorption increases with increasing dimensions of timber. The maximum increase in load with increasing the depth of timber (72.5%) when the thickness of timber Change from (85 to 190) mm.

1. Introduction

Variety building materials are used in civil engineering constructions. The mechanical properties, durability, availability, workability and other factors could be effect on selecting the suitable material. The materials also behave in different manners as a response for the applied loads. Generally, Most of the materials available do not meet all structural requirements. Therefore, the engineers seeking for arranging the different materials in a specific style in order to obtain the best geometry, by placing the materials in locations that have their distinctive properties (e.g. concrete in compression and steel in tension). This is the main reason for employing more than one component of different materials to



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achieve full merit of their property in getting structural member in which utilized only the desirable material properties. The member is then known as a composite member. The structural performance of composite member depends on the possibility of connecting the composite components together. In general, the composite structures, have higher load capacity and stiffness compared with non-composite counterparts and subsequently the overall depth of composite sections will be reduced. Steel and concrete are the widely materials used in different applications of civil engineering [1]. On the other hand, timber is often used for structural purposes in civil engineering applications for many years and it considers a rival to other conventional building materials, because it has a lightweight beside high strength as well as it's a sustainable material [2] Combined timber with concrete is consider the wellknown form in structural field. Many experimental and numerical studies have been conducted on timber-concrete composite structures [3, 4]. Recently, timber could be combined with other materials such as glass [5, 6] and steel [7, 8] were utilized to create composite members. Timber-timber composite members were also presented by researchers to obtain new light weight composite members [9, 10]. Ferrocement deem a thinned concrete element (i.e. 50 mm maximum thickness) has a high tensile strength-to-weight ratio and superior cracking behaviour compared with conventional concrete. It is used in wide spectrum of civil engineering applications [11]. The researchers aimed to employ the available and effective ideas coming from technology and other aspects of the life for conduct their works. The suitable properties of timber and ferrocement as well as to composite action advantages have stimulated the authors to present and deals with the composite beams that consist of timber and ferrocement components and using their respective merit to the ultimate extent. Therefore, the main goal of the present study is to produce data and supply information about the structural conductance of new proposed member which consists of ferrocement and timber. For this purpose, the eleven samples of timber ferrocement composite beams connected by epoxy adhesive. The region of bending moment, hogging and sagging, are also explored to assess the effect of this variable on the behaviour of timber ferrocement composite beam. This study also includes, push-out test is suggested to examine the strength and behaviour of the used epoxy adhesive.

2. Experimental program

2.1. Material properties

All materials used (cement, sand, water, wire mesh, epoxy and timber) for all specimens were the same along the investigation. The details of these materials are presented below: Timber (Rad wood) was used as one of the types of timber utilized in constructions which is characterized by hardness, durability and strength. The tests were conducted for used timber in accordance with ASTM – D 198 – 84[12]. The geometrical details are shown in Table (1). The results of physical and mechanical properties of timber were given in Table 2 Figure 1, shows the test setup of timber samples. Locally available steel wire mesh was used throughout this investigation. The dimensions of wire mesh were (0.8 and 12) mm for square opening and wire diameter, respectively. The mechanical properties of wire mesh were determined from testing three coupons of the wire were taken from mesh roll under direct tension according to ACI Committee 549[13], as shown in Figure 2. The average tensile strength, ultimate strength and Young's modulus of tested coupons were 325 MPa, 480 MPa and 200 GPa, respectively. The material properties obtained for used steel wire mesh are summarized in Table 3.

Sikadur-31 Thixotropic Epoxy Resin Adhesive was used which is a solvent-free, thixotropic, two components epoxy resin and hardener (A and B). The two components (A and B) are mixed in ratio (1:2) by weight together with a mixing paddle attached to a slow speed electric drill as recommended by manufacture. The mixing continue until the material becomes smooth in consistency and even grey in colour. The flexural, compressive strengths and modulus of elasticity of used epoxy (Sikadur 31) were 37 MPa, 42 MPa and 43 GPa, respectively.

o	Timber b	Timber beam		Ferrocement slab		Length	Bending
lqm –	Depth	Width	Width	Depth	of mash	In mm	moment
Sa	in	in	in	in			
	mm	mm	mm	mm			
T-F7	135	85	400	50	5	2400	Sag
TF8	135	85	400	50	5	2400	Hog
TF9	135	85	400	50	5	2400	Sag
TF10	85	85	400	50	3	2400	Sag
TF11	135	85	400	50	5	2400	Sag
TF12	85	85	400	50	5	2400	Hog
TF13	190	85	400	50	5	2400	Sag
TF14	85	190	400	50	5	2400	Sag
TF15	190	85	400	50	5	2400	Hog
TF16	85	135	400	50	5	2400	Hog
TF17	190	190	400	50	5	2400	Sag

Table 1. Details of specimens.

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

Property	Moisture content %	Specific gravity	Compression perpendicular to grains (tangential) MPa	Compression perpendicular to grains (radial) MPa	Compression parallel to grains MPa	Modulus of elasticity MPa	Flexural strength MPa
Test results	3.27	0.67	8.6	12.667	40.6	19788	69



a Figure 1. a- Compressive parallel to the gain.





b- Compressive perpendicular to the gain.

c- static bending test.

Specimens	Wire diameter (mm)	f _y (MPa)	f _{ul} (MPa)
W1	0.8	331	480
W2	0.8	316	454
W2	0.8	330	472
average	0.8	325	468

Table 3. Properties of wire mesh.

The cement mortar consists of ordinary Portland cement and natural sand passing from the sieve 2.36 mm were used in this research. The ratios of cement to sand and water to cement were 0.5 and 0.325, respectively. The drinking water was used in the experimental work of mixing and processing. The 28-day average compressive strength of mortar was 60 MPa.

All specimens were cast at the same time and stored in the same ambient conditions. The tested ferrocement-timber composite (FTC) beams are of 1200 mm and 2400 mm overall length. Four different cross-sections of timber were utilized which included (85×85) mm, (85×135) mm, (85×190) mm and (190×190) mm. The dimensions of ferrocement panel were 50 mm in depth and 400 mm in breadth. The layers of wire mesh were six or three i.e. (volume fraction is 0.8%), respectively.



Figure 2. Stress-strain relationship for wire mesh.

2.2. Fabrication

Precast ferrocement panels were cast using plywood sheet molds having a nominal thickness of 12 mm. The long sides of the molds have sets of holes defining the position of the layers of mesh. The three and six layers of steel meshes were tied together using very fine steel wires and fixed to the mold through these holes. All specimens were tested after 30 days. In addition, timber members were prepared and cut with the required dimensions. The sides of timber members and ferrocement panel at which they connected were well cleaned. Then, the two components of composite beam, timber beam and ferrocement panel were joined together using epoxy adhesive (Sikadur 31). The thickness of epoxy layer was almost 3 mm. Next, the two components were pressed using a mechanical fastener prepared for this purpose along three days. The casting process of ferrocement members and assemblage of ferrocement with timber are illustrated in Figure 3.



Figure 3. Configure of specimens.

2.3. Push out test

The connections between the ferrocement panel and timber beam should be checked through achievement of push out test. There is no codes or specifications concerned with push out test for adhesive bonding ferrocement-timber composite (FTC) members. Therefore, the model presented in this study was suggested according to British specification for steel-concrete composite beam. For this purpose, samples of push out test were made in two fashions. In the first fashion, the prepared push out sample consists of two segments of ferrocement with dimensions $(400 \times 300 \times 50)$ mm and one segment of the timber with dimensions $(400 \times 135 \times 85)$ mm (PUSH1). While, in the second style, it consists of two segments of timber and one segment of ferrocement with similar dimensions of the first fashion (PUSH2). Figure 5 illustrates the dimensions and styles of push out tests. As mentioned earlier, the samples were bonded with 3 mm epoxy adhesive and pressured by a mechanical clip and leave it for three days prior to the examination. The tests were done using the Universal Testing Machine (MARUI) 20-ton capacity. Load was applied on the specimen in constant increments at each load level up to the ultimate load, while the slip between the timber and ferrocement segments was measured. The dial gages were positioned to measure the slip at the interface of ferrocement and timber. The detailed and results of tested push-out specimens are summarized in Table (4). The failure modes of specimens were observed for both specimens. In the first failure mode of PUSH1, a thin layer of mortar was separated from ferrocement segment and remained attach to the timber section in the interface region. On the other hand, the second mode of failure of PUSH2 was characterized by splitting the timber section as shown in Figure 6. This indicates that there is no any debonding occurs between the two components (ferrocement and timber) and the adhesive epoxy layer provided an adequate bond between them. Hence, the bond using Sikadur 31 could considered to be perfect. Figure 6 illustrate failure of push-out specimens.



Figure 4. Push out specimen.

No.	Specimens designatio n	Epoxy Layer thickness	Period of hardening of epoxy layer (days)	Failure mode	Total ultimate load (kN)	slip at ultimate load (mm)
1	PUSH1			Ferrocement splitting at adhesive region	134	4.8
2	PUSH2	3 mm	3	Timber splitting at adhesive region	175	8

Table 4. Ultimate values of load and slip in push-out test.



Figure 5. Dimensional drawing of Push out specimen.



Figure 6. Failure of push-out specimens.

2.4. Test of Specimens

A day before testing, all specimens of composite beam were prepared for testing. The total number of tested specimens in this program were eleven specimens. One specimen of them was timber beams, and another one was ferrocement penal. The load on beams was applied monotonically in increments. These

increments were reduced in magnitude as the load reaches the ultimate load. TORSEN universal testing machine with capacity of 600 kN was used to apply the load. The load was applied at the mid-point of beam span as shown in Figure 7.



Figure 7. Testing setup.

3. Results and discussion

3.1. Failure modes

Figures 9 to 15 shows the results of the study of the composite ferrocement timber beam. The mid-span deflection from the laboratory tests is shown in Table 5 and 6. While Figure 8 and 9 show a number of models after the failure process.

Various modes of failure are observed during the static tests of the composite beams. The global response of load-deflection relationship of composite beams shows a linear elastic stage followed by a nonlinear behaviour. Under serviceability limit state conditions, no cracking is detected during the loading period. After the initiation of flexural cracks, the stiffness of beams reduces and the linear loaddeflection behaviour vanishes when the internal steel wire mesh begins to yield. The non-connected composite beam (TF-7) suffered from excessive tensile cracks in ferrocement at the end of the linear behaviour of timber beam while bending in timber continues to increase, then cracks begin in the timber beam at the mid-span towards the support until the stage of failure. The composite beam specimens subjected to sagging bending moment (The ferrocement is at the top and the timber at the bottom failed firstly by the cracks in the ferrocement at mid-span tension zone). Then cracks begin in the timber where there is almost a small incision in the middle in the tension zone begins to grow by increasing force. Then the cracks in the ferrocement will be displayed as well as in the timber and small cracks will begin in the epoxy bonding area. The failure cracks are occurring in the middle third region. Beams with sagging bending moment tensile failure in the timber beam but cracks started from the bottom surface of timber beam at the mid-span and propagated upward with an angle between 35° to 47° with the horizontal. After increasing the load, the cracks extended towards the support.

Figure 10. shows the load midspan deflection relationships for composite beam without adhesive layer (T-F7) compared with composite beam that connected by adhesive layer and same dimensions (TF11). It can be seen the load is increase from 60 kN for TF-7 to 82 kN for TF11 with a reduction ratio 26.8% and also the deflection is increase from 13 mm for TF-7 to 18 mm for TF11 with a reduction ratio 27.7%. It can be notice that a clear increase of load and deflection when using of epoxy as a bond between the individual parts (timber beam and ferrocement panel). On the other hand, the composite beam subjected to hogging bending moment (timber is at the top and the ferrocement is down) the failure of beams in this case, is characterized by cracking in the tension zone of ferrocement slab and increasing deflection with a drop-in load. After that, the cracks propagated upward to the top surface of ferrocement slab. The crack width increased with the increase of the applied load and leading to failure of specimens. we noticed a crack in the middle of the ferrocement but the composite beam still did not fail. This indicates that a crack in the ferrocement was to obtain homogeneity between the strains beyond (0.003) for ferrocement. No local buckling in the timber beams was noticed at the failure of these composite beams.

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• Beams Under Sagging Bending

Each of ferrocement slab and timber beam has its own deflection value due to uplift (separation between the components), the deflection values of ferrocement slab and timber beam are approximately equal [29]. Table (5-4) shows the related results.

Figure 11. show load mid-span deflection relationships for composite beams (TF10, TF11 and TF13) with different timber beam depth (85mm,135mm and 190mm) respectively, with the same width. The extrapolated deflection value at ultimate load decreases from 18.45 mm to 18 mm to 14mm respectively, with a reduction ratio of 24% and 23%. While the ultimate load decreases from 120 kN to 82 kN to 33 kN respectively. With a reduction ratio of 33.33% and 72.5%. So, when the depth of timber increases, the ultimate load increases and the midspan deflection decreases.

Figure 12. show load midspan deflection relationships for composite beams with different timber beams width (85 and 190) mm and the same depth 85mm when the width increases from 85 mm for beam TF10 to 190 mm for beam TF14 the extrapolated deflection value at ultimate load increase from 17 mm to 18.45 mm with increase ratio of 8.2%. While the ultimate load Increases from 33 kN to 74.5 kN respectively.

Figure 13. Show load midspan deflection relationships for composite beams (TF17 and TF13) with different timber beam width (85mm and 190mm) and the depth is equal (190mm). The extrapolated deflection value at ultimate load decreases from 29 mm for TF17 to 14 mm for TF13, with a reduction ratio of 51.7%. And ultimate load decreases from 270 kN to 120 kN with a reduction ratio of 55.5%. So, there is a big and noticeable change in ultimate load and deflection in the case of the large depth timber. Figure 14. Shows the load midspan deflection relationships for composite beam with (5 and 3) layers of wire mash in ferrocement slab TF9 have 3 layers of wire mash and TF11 have 5 layers of wire mash and same dimensions of composite beams. The load is increase from 53 kN for TF9 to 82 kN in TF11 with a reduction ratio of 35.4%. And also the deflection is increase from 12 mm for TF9 to 18 mm for TF11. with a reduction ratio of 33.3%.

• Beams Under Hogging Bending

The failure of beams in this case is characterized by cracking in the tension zone of ferrocement slab and increasing deflection with a drop-in load recorded by the testing machine. The first crack appeared at the bottom surface of ferrocement slab when the load almost reaches (0.3Pu). After that, the cracks propagated upward to the top surface of ferrocement slab at the load nearly approaches (0.6Pu). The results of sample are shown in table 6. The crack width increased with the increase of the applied load and led to failure of specimens.

Figure 15. shows the effect of the depth of timber section on load-midspan deflection response for composite beams tested under hogging bending. The depth of timber beams is (85, 135 and 190) mm for composite beam (TF12, TF8 and TF15) respectively, while the width of those samples is equal. The ultimate load is increase by 11 % and 53%, respectively. While the maximum deflection of these beams variation of deflection ranged 13% and 23%, respectively.

Figure 16. show the effect of the width of timber section on load-midspan deflection response for composite beams tested under hogging bending. The width of timber beams is (85 and 135) mm for specimen TF11 and TF16 respectively, while the width of those samples is equal. It can be seen that the ultimate load is increase by percentage 7.9 %. While the maximum deflection of these composite beams increased by percentage 7.7%.

No	Beams designation	Ultimate load (kN)	Ultimate moment (kN.m)	Mid-span deflection at ultimate load (mm)	Service Load (kN)
1	T-F7	60.0	34.05	13.00	40.0
2	TF9	53.0	30.07	12.00	35.3
3	TF10	33.0	18.72	18.45	22.0
4	TF11	82.0	46.53	18.00	54.6
5	TF13	120.0	68.10	14.00	80.0
6	TF14	74.5	42.27	17.00	49.6
7	TF17	270.0	153.22	29.00	180.0

Table 5. Experimental results of tested sagging composite beams.



Figure 8. SpecimenTF9 after failure.

	l able 6.	Experimental resu	ilts of tested hogg	ing composite bea	ims
	Beams	Service	Ultimate	Ultimate	midspan
No.	designation	Load (kN)	load (kN)	moment	deflection at
				(kN.m)	ultimate load
					(mm)
1	TF8	24.3	37	20.99	17.0
2	TF12	23.0	35	19.86	19.5
3	TF15	53.3	80	45.40	15.0
4	TF16	25.3	38	21.56	18.0



Figure 9. composite beam under hogging bending after failure



Figure 10. Variation of midspan deflection for composite beams without shear connecter and with connecter.



Figure 12. Variation of midspan deflection with load for composite beams the variable is timber (8.5X8.5) (8.5X19).



Figure 14. Variation of midspan deflection with load for composite beams the variable is number of wire mesh.



Figure 11. Variation of midspan deflection with load for composite beams the variable is timber depth.



Figure 13. Variation of midspan deflection with load for composite beams the variable is timber (19X19) (19X8.5).



Figure 15. The effect of timber beam depth on variation of midspan deflection With load for composite beams hogging moment.



Figure 16. The effect of timber beam width on variation of midspan deflection with load for composite beams hugging.

4. Conclusions

The suggested dimensions and properties for push-out tests may be considered as the standard test for connectors in ferrocement-timber composite beams according to the failure type. The failure of push out specimens occurred in two modes. In the first, a longitudinal crack in timber beam occurred along the full length of the beam. Also, a failure in the binding area leads to the separation of one of ferrocement slab with the survival of some parts of the ferrocement connected with the epoxy. Composite timberferrocement beams (FTC) exhibited high increase of section capacity as compared with timber beams. The ferrocement slab used is thin (50 mm), the composite sections overall stiffness and strength increase with a high ratio. The strength range increase ratio (2.33), while the composite beam with full connection compared with composite beam without connection explained that there is an increase ratio in strength ranges (1.64). For composite beams under sagging bending when the depths of timber section are (85 and 135) mm, a failed by flexure in the tensile zone of timber beam. The failure that occurred is due to a crack in the timber beam started from the bottom surface of the timber at the mid-span and propagated upward with an angle between 35° to 47° with the horizontal. When the depth of timber beam is 190 mm, a failed by flexure in the tensile zone of timber beam and occurs parallel to the timber fiber and if the thickness of the timber increases, the strength increases significantly and the deflection increases but with rates almost equal. The addition of steel weir mash to the ferrocement slab can delay the initiation of crack and led to a significantly increasing of ultimate carrying capacity, ductility and energy absorption of specimens. Under serviceability limit state conditions, no cracking is detected during the loading period. After the initiation of flexural cracks, the beams stiffness reduces and the linear load deflection behavior vanishes when the internal steel wire mesh begins to yield.

5. References

- [1] European Committee for Standardization, EN 1994-1-1, Eurocode 4, 2004 Design of composite steel and concrete structures – Part 1-1: General rules and rules for buildings. Brussels.
- [2] A. M. Harte, 2009 Timber engineering: an introduction, [in:] M. Forde [Edit.], ICE Manual of Construction Materials, Chapter 60.
- [3] M. Szumigała, E. Szumigała, Ł. Polus, 2018 Laboratory tests of new connectors for timber-concrete composite structures, Eng. Trans. 66 (2), 161–173.
- [4] E. Łukaszewska, H. Johnsson, M. Fragiacomo, 2008 Performance of connections for prefabricated timber-concrete composite floors, Mater. Struct. 41, 1533–1550.
- [5] M. Kozłowski, M. Kadela, J. Hulimka, 2016 Numerical investigation of structural behavior of timber- glass composite beams, Procedia Eng. 161, 78–89.
- [6] K. Rodacki, K. Furtak, 2019 Numerical analysis of crack development of timber-glass composite Ibeams in the extended finite element method (XFEM), Compos. Struct. 209, 349–361.

- [7] S. Stiemer, S. Tefamariam, E. Karacabeyli, M. Popovski, 2012 Development of steelwood hybrid systems for buildings under dynamic loads, Behaviour of Steel Structures in Seismic Areas STESSA 2012, January 9 – 11, Santiago, Chile.
- [8] W. Winter, K. Tavoussi, T. Pixner, F. R. Parada, 2012 Timber-steel-hybrid beams for multi-story buildings, World Conference on Timber Engineering, 16-19 July, Auckland.
- [9] European Committee for Standardization, EN 1995-1-1, Eurocode 5, 2004 Design of timber structures Part 1-1: General Common rules and rules for buildings, Brussels.
- [10] EN 26891, 1991 Timber structures Joints made with mechanical fasteners General principles for the determination of strength and deformation characteristics.
- [11] S. F. Resan, 2012 Structural Behavior of Simply Supported Ferrocement Aluminium Composite Beams, Ph. D. Thesis, College of Engineering of The University of Basrah, February.
- [12] American Society for Testing and Materials, ASTM D 198, 1984 Standard Test Methods of Static Tests of Lumber in Structural Sizes.
- [13] ACI Committee 549, "Guide for the Design, Construction, and Repair of Ferrocement", ACI 549.1R-93.