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Evaluation of flexural strength of concrete beams reinforced with timber encased in permanent ferrocement forms

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Abstract

A structural element must exhibit strength and stability for its intended use. This paper presents an investigation of a concrete beam reinforced with timber and encased in permanent ferrocement form for use as lintels for low-income housing. The 25 mm thick cement-sand ferrocement is reinforced nominally using a two-layered chicken mesh. The timber is placed in the tensile zone and the concrete cast around it is assumed to act in compression. The specimens were tested under a single-point flexural loading. The concrete design strength was 20 N/mm^2 at 28 days. The induced loadings computed on the beam included the triangular load from the blockwalls and the self-weight of the concrete beam at the ultimate limit states which yielded a maximum bending moment of 0.22 KNm. However, the maximum carrying capacity based on first crack load yielded a maximum bending moments of 9.10 and 10.20 KNm for 50 x 50 mm and 50 x 75 mm timber reinforced ferrocement beams respectively. The computed maximum bending stress at the bottom of the fibre assuming uncased isotropic timber beams are 9.67 and 4.29 N/mm^2 for the 50 x 50 mm and 50 x 75 mm timber respectively which is less than 10 percent of the ultimate bending strengths of the timber specimen. The results of the ultimate carrying capacity achieved would enable a choice of the size of timber beams positioned in the tensile zone of the permanent ferrocement forms to be made.

Keywords: carrying capacity, lintels, permanent ferrocement forms, timber reinforcement, chicken mesh

1.0 Introduction

1.1 Lintels as a structural member

A lintel is generally used to carry loads in flexure from windows and doors openings. They are regarded as beams acting in flexure by the mechanism by which they carry their loads and the requirements for the design and detailing are covered in the relevant codes such as BS 8110 and BS EN 1992 [1, 2]. Blockwalls' over where lintels are laid are regarded as a slender member, because of its high ratio of the length to the height, referred to as slenderness ratio. The requirements for walls design are covered by many design codes such as the BS 5628-2: Part 1: 2005 [3]. Basic functional requirements to be satisfied are strength and stability.

The quest for a more economical designs or solutions that will speed up construction time and satisfying acceptable or higher working stress levels is the ultimate goal. It must avoid excessive crack widths and that deflection should be within acceptable limits, which is ultimately more critical than strength concerns. This material of interest is particularly suited for thin-walled construction to provides better crack resistance, higher tensile strength to weight ratio, ductility and impact resistance.

The paper aims to present the carrying capacity of concrete beams reinforced with timber in the tensile zone of the beam encased in permanent ferrocement formwork. It also outlines basic construction procedures and the opportunity of exploring wealth creation using this construction technique along the value chain.

1.2 Ferro-cement

Ferrocement can be described as a class of thin reinforced concrete/mortar consisting of a nominal or large amount of small diameter meshes which are distributed uniformly within a matrix of cement-sand mortar mix. It possesses a unique quality of strength, low self-weight, homogeneous mechanical properties and serviceability when

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compared with the same thin thickness using conventional reinforced concrete which uses larger diameter reinforcing bars, [4,5,6]. In the production of permanent ferrocement lintel, no temporary formwork is required thereby reducing skilled labour hours in the production process.

1.3 Components of ferro-cement

Ferrocement primarily consists of the cement-sand composite placed by plastering or by shotcreting. The wire mesh reinforcements consist of galvanized chicken mesh wires, expanded wire mesh or steel mesh reinforcements

1.3.1 Mortar

Conventional cement-sand mortar is a composite material obtained by mixing cement, fine aggregate and water. The knowledge of both its wet and hardened properties is fundamental, [7, 8, 9, 10]. Cement-sand mortar is commonly used as basic finishing material on block walls such as plastering, rendering and/or on screeded beds. The basic properties of the constituents include particle size distribution, specific gravity, shape and surface texture. The ratio of cement:sand ranges between 1:2 to 1:3 by weight and mixing water to cement ratio between 0.4 to 0.6 by weight for plastered finishes and up to 0.7 for on-site placing into moulds, [9, 10]. The thickness of the thin element ranges between 10 – 25 mm thick. The composite material may also include admixture to alter the properties of the mix either in the wet or hardened states. Admixtures such as super-plasticizers and water repellant additives are in common use. Often, smaller diameter bars may be incorporated particularly where axial tension is the primary structural concern as in the case of surface circular tanks.

1.3.2 Wire mesh reinforcements

The mesh reinforcements consist of two (2) or more layers of thin diameter mesh wires. Different types and proprietary products are available such as woven or welded mesh, perforated sheet products and expanded metal lath. Shape like hexagonal to square shapes are used as reinforcements and are usually galvanized which make them resistant against rust and alkalis except expanded metal mesh products.

1.4 Properties of ferro-cement

Ferro-cement is an extremely very thin reinforced member with thickness between 10 -25 mm. Where low load structural application is required, the thin mesh reinforcements act as crack arresters. Properties of ferro-cement materials include, tensile, cracking, compression and durability characteristics. Other properties are liquid retaining capacity, fire resistance and impact resistance [4]

1.4.1 Tensile behaviour

Like any structural material, the strength characteristics, the stress-strain relationship is quite unique despite being an extremely thin material. The tensile behaviour is depended on the type and layers and shape of wire mesh reinforcement used, [4, 11, 12, 13, 14]. The tensile behaviour of ferro-cement is different from the conventional larger diameter steel reinforcements. The specific surface of the mesh reinforcements is higher and they are uniformly distributed within the matrix.

Al- Rifaei *et al*. study on the ultimate flexural load of ferrocement slabs and reported that increasing the number of mesh layers from 1-3 caused a substantial increase in flexural load as well as improvement in ductility behaviour of ferrocement slabs, [11]. The cracking pattern and behaviour depend on volume and interfacial bond of the mesh reinforcements in the cement-sand mortar matrix. The visible first crack pattern, either microscopic or with naked eyes can be observed when measuring load deflection test. The values normally depend on the specific surface or volume of the mesh wires. Investigation has shown that the stress-strain curve first behaves as a linear elastic material until first crack appears. Multiple cracks propagate after the first crack as the load increases while the crack width remains constant and propagates in the direction where the matrix starts to fail, [16].

1.4.3 Compression

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Compression characteristics in a ferro-cement composite is largely due to the compressive strength of the cement -sand mortar matrix. Increase in number of mesh layers also increases the compressive strength and typical compressive values between 30 – 70 N/mm^2, [15, 16]. However, splitting of the laminates and buckling of the mesh reduces the compressive strength. Compressive strength is also affected by the type of mesh reinforcements and laminates made with welded mesh provides higher strength.

1.4.4 Durability

Exposure to environmental factors when in use determines its performance in service. Mechanical strengths, permeability, exposure to weather and hostile environments are comparable with characteristics exhibited by conventional reinforced concretes. The quality of the cement-sand mortar used affects considerably the durability of the composite material but the thin layer of mortar cover makes it susceptible to corrosive agents. Most thin wire mesh produced are galvanized thereby reducing the effect of corrosion. A low water-cement ratio and addition of admixtures or mineral additives would reduce porosity and increase the resistance to permeability, [4].

1.4.5 Liquid retaining capacity

The common areas of application of ferro-cement are its impermeable characteristic behaviour. This has made the composite material popular in circular water storage tanks retaining structures where the mesh reinforcements act as crack arresters. Circular shapes further make use of structural action using axial tension. Crack widths formed in ferro-cement are much smaller than those in reinforced concrete subjected to flexure, [4].

1.4.6 Fire resistance

Study has shown that resistance to fire increased when structural columns are jacketed with ferro-cement laminates. The specific heat capacity increases more than the conventional concrete cover provided on concrete structures thereby preventing spalling of concrete covers which occurs in conventional reinforced concretes. Increase in number of mesh layers also increase toughness, [4].

1.4.7 Impact resistance

Ferro-cement elements are known to possess some high energy absorption characteristics apparently because of the high specific surface of mesh reinforcements. Addition of silica fume and fly-ash to the cement-sand mortar matrix is also known to increase its energy absorption capacity which is usually localized around the point of contact [13].

1.5 Uses of ferro-cements

Uses of ferro-cement include:

- Surface water tank structures
- Fire resistant applications
- Concrete repair works
- Boat building
- Sculpture works
- Pre-cast permanent formworks
- Cisterns

1.6 Classification of lintels

Lintels are classified based on type of materials as:

- Reinforced concrete lintels
- Timber Lintels
- Stone Lintels
- Brick Lintels
- Reinforced Brick Lintels

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- Steel Lintels

In all the types, excessive cracks and deflection must be avoided so as not to impair the appearance of the structure.

Avoid corrosion of the embedded steel or the reinforcing mesh particularly in aggressive environment.

2.0 Materials and methods

2.1 Fine aggregates

In accordance with BS 812 [17], fine aggregates otherwise called sand are generally described as aggregates Passing 4.75mm aperture size openings and retained on 75microns irrespective of their source and is required to be free from silt, clay and any deleterious substances. BS EN 933-1: 2012, [18] uses three classifications for sand which include coarse sand with grain size within 2 to 4.75 mm range, medium sand with grain size within 0.425 to 2 mm range and fine sand with grain size up to 0.425 mm. Fine sand is used with the size grading fitting into the mesh openings. Two classes of fine aggregates used are shown in Figures (1) and (2) representing plaster sand used for the ferrocement form and medium sand used for casting the concrete beam respectively.

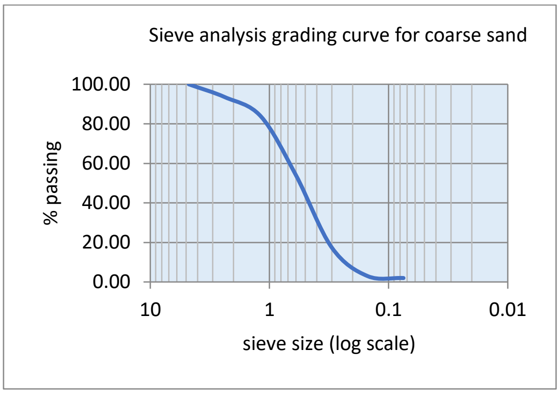

Figure 1: Grading curve for coarse sand

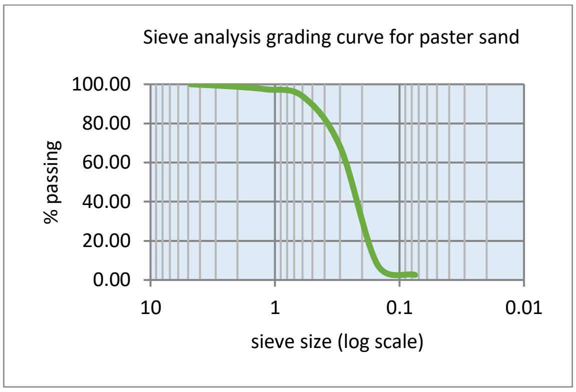

Figure 2: Grading curve for plaster sand

2.2 Cement

Portland cement is the binder and is generally a calcareous (lime) and an argillaceous (silica and alumina) material, [19]. It is used for bonding aggregates and fragments together in this cement-sand composite material. Cement is manufactured in accordance with BS EN 197-1, [20].

2.3 Timber

Timber for use as lintels is considered structurally weak, vulnerable to fire and can easily decay when used freely And un-protected, [4]. Encasement in ferrocement form provides protection against fire, termite attack fungus attack and moisture. The iron wood species is soft and workable when freshly felled but hard, termite resistant and difficult to work when dry. They are hardwoods and are available in most timber sheds. Timber properties generally vary with species, age, soil and environmental conditions, [21, 22, 23, 24].

Strength of timber is usually characterized as stress parallel and stress perpendicular to grain, [22]. The wood used here is refered to as the African birch wood, locally known as Ayin (Yoruba), Marke (Hausa) Atara (Igbo). They belong to the family "*Combretaccecae*" and botanical name is "*Anogeissus leiocarpus*". African birch timber belongs to strength class of D30 – D70 and is considered as a hardwood which makes it suitable for structural applications.

2.4 Mesh reinforcement

Small diameter and galvanized two layers of chicken meshes are distributed uniformly within a matrix of cement-sand mortar mix. It is also common to use galvanized expanded wire mesh.

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3.0 The model

3.1 Load carrying mechanism of lintels

The load carrying mechanism of lintels are illustrated in Figures (3) and (4), [25, 26]. The distribution of the dead loads include:

- Triangular dead loads from the bricks
- The self-weight of the lintel
- Point load from support reactions from the roof truss

The point load from the support reaction can however be converted to an equivalent uniformly distributed load on the lintel as shown in Equation (1).

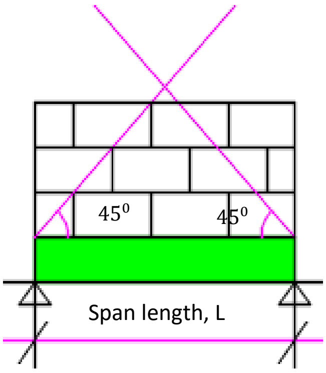


Figure (3): Triangular dead load

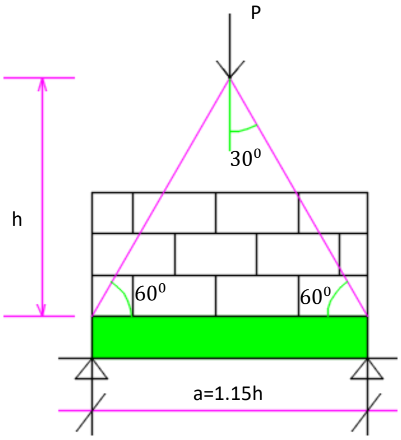


Figure (4): Point load from support reactions on lintel

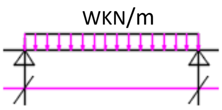
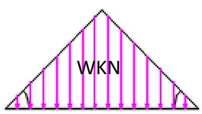
$$wp = \frac{P}{a} \qquad (1)$$

Where:

P = Load from roof truss
a = Span length approximated as 1.15h
h = Height of projected inclination at angle 60^0 for point load from roof truss
wp = Equivalent UDL of point load P

The loading, maximum bending moment, maximum shearing force and maximum deflection are depicted in Table (1).

Table 1: Table of end actions and maximum deflection on rectangular shaped lintels

Loading	Maximum Bending Moment	Maximum Shearing Force	Maximum Deflection
	$\frac{wl^2}{8}$	$\frac{wl}{2}$	$\frac{5wl^4}{384EI}$
	$\frac{WL}{6}$	$\frac{W}{2}$	$\frac{WL^3}{60EI}$

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3.2 Load carrying capacity of timber lintels

An imposed load on a lintel exerts a bending moment which also cause deflection in the beam as a result of the internal stresses at every cross section of the beam. By exploring the properties of a homogeneous material in bending, [27], the following assumptions are made:

- The material used is homogenous and isotropic
- The material is stressed within its elastic limit, thus obeying Hooke's law
- The transverse section is plain before and after bending
- The value of the Young's modulus of elasticity of the material is the same both in tension and compression
- There is tension and compression at the outermost fibres of the beam causing the beam to be in equilibrium

The general expression of bending strength for an isotropic and homogeneous beam is given in Equation (2) as, [27].

$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R} \qquad (2)$$

Similarly, maximum bending stress f_b at the bottom of the fibre can be expressed in Equation (3) as:

$$f_b = \frac{6M}{bd^2} \qquad (3)$$

The maximum shear is thus expressed in Equation (4) as:

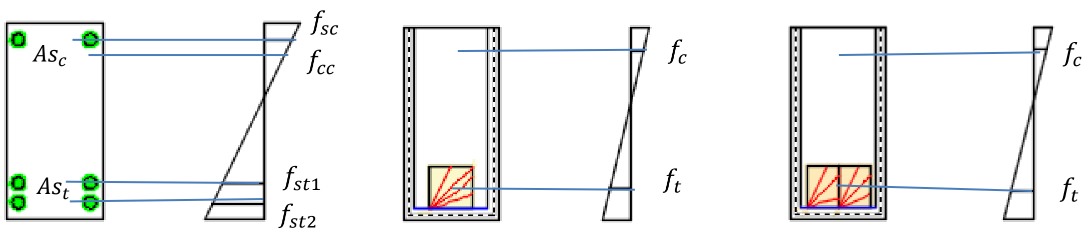
$$f_v = \frac{3V}{2bd} \qquad (4)$$

The expressions in Equations (3) and (4) are expected to be below limiting values of the permissible values for an isotopic material

Where:

M = Maximum bending moment in the beam, I = Moment of inertia, E = Young's modulus of elasticity
σ = Maximum stress in the beam, R = Radius of curvature, y = Distance to the neutral axis of the timber beam

The distribution of stresses and strains across a beam can also be idealized in the stress diagram shown in Figures 5(a) – (c), [25] which can be estimated by evaluating the equilibrium conditions. This can be achieved by multiplying the limiting stress in a material in both the tensile and compression by the corresponding lever arm length which can be scaled graphically, and the capacity can thus be obtained using the expression in Equation (5)



(a) (b) (c)

Figures 5(a)-(c): Distribution of stress/strain diagram for typical rectangular composite beam

The theoretical moment of resistance or the carrying capacity for a typical reinforced concrete beam section can thus, be estimated as the summation of the force, multiplied by the lever arm as in Equation (5):

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$$M_u = F_{cc}z_1 + F_{st}z_2 \quad (5)$$

where:

$F_{cc} = f_{cc}A_c$ (Force in compression)
$F_{sc} = f_{st}A_{st}$ (Force in tension)
Ac = Area of concrete in compression
Ast = Area of steel/timber in tension

and partial factor of safety on the material as in steel should be applied, such as:

$$f_{st} = \frac{f_y}{\gamma_m}, \qquad f_{sc} = \frac{f_y}{\gamma_m + \frac{f_y}{2000}}$$

4.0 Results and Discussion

4.1 Carrying capacity of the ferrocement beam

The test results carried out on the concrete beam encased in permanent ferrocement formwork is shown in Table 2. The 3-number of beams are reinforced with 50 x 50 mm and 50 x 75 mm timber placed in the tensile region of the beam of size 150 mm x 225 mm as shown in Figure 5(b). The first crack and ultimate failure loads were recorded accordingly. Concrete compressive strength was 20 N/mm^2. The cement:sand mortar mix ratio is 1:3 at water cement ratio of 0.7 at saturated and surface dry condition while the compressive strength is 13.2 N/mm^2. The thickness of the permanent ferrocement for was 25 mm.

Table 2: Test results on the ferrocement beams

Specimen ID	First Crack Load (F_{CL})		Ultimate Load (F_{UL})		Ratio: F_{CL}/F_{UL}	
	Individual	Average	Individual	Average	Individual	Average
BM-22A	40.5		56.7		0.7	
BM-22B	42.5	40.4	46.5	51.5	0.9	0.8
BM-22C	38.2		51.2		0.7	
BM-23A	52.4		72		0.7	
BM-23B	35.3	45.3	50.7	61.7	0.7	0.7
BM-23C	48.2		62.3		0.8	

(All values in KN)

4.2 Characteristic behaviour under load

The testing pattern and the permanent ferrocement formwork are as shown in Figures 6(a) – (c) consist of the test specimen on two supports with a central point load and tested at a loading rate of 100 mm/min. The first crack load is also noticeable with a knocking-like sound while the ultimate failure load is much higher. The cracking of the ferrocement signals the failure but the timber reinforcement in the tensile zone does not break even at ultimate load since it is an elastic material.

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(a) (b) (c)

Figure 6(a)-(c): Test specimens, temporary steel formwork and the permanent ferrocemet form

4.3 Carrying capacity of the ferrocement beams

The theoretical carrying capacity (Mmax – F_{CL}) at first crack load was estimated as shown in column (2) of Table 3 since the test sample was a central point load. The maximum theoretical moment carrying capacity, assuming load are to be carried by the timber beam alone without being encased in the ferrocement form based on the triangular loads from the blockwalls for the 0.9m span are shown in column (3) of Table 3. The loads are computed based on the loading condition in Figure (3) and the maximum bending moments are computed based on Table (1). These maximum bending moment values shows that loads being carried by lintels are very low. Similarly, the theoretical bending strength in service based on Equation (3) is shown in column (4). It shows that the higher the value of the sectional modulus, the higher the bending strength implying that bigger cross-section of wood implies higher carrying capacity. Bending strength f_b values of 80.5 N/mm^2 and tensile strength f_t value of 99.67 N/mm^2, were recorded for the Ayin timber [25]. The carrying capacity in Equation (5) using $0.45f_{cu}$ [26] is shown in column (5) which does not adequately predict the carrying capacity because of the reduced area of concrete in compression and reduced lever arm.

Table 3: Carrying capacity of ferrocement beams

(1)	(2)	(3)	(4)	(5)
Specimen ID	Mmax-F_{CL}	Mmax-F_{IND}	Maximum stress (f_b)	Mmax (Theoretical)
	$\frac{PL}{4}$ KNm	$\frac{Wl}{6}+\frac{wl^2}{8}$ KNm	$\frac{6M}{bd^2}$ N/mm^2	$M_u = F_{cc}z_1 + F_t z_1$ KNm
BM-22	9.1	0.22	9.966	8.375
BM-23	10.2	0.22	4.429	7.80

*BM-22: Beam ID 50 x 50 mm. *BM-23: Beam ID 50 x 75 mm

Conclusion

African birch timber belongs to strength class of D30 – D70, [22] and is considered as a hardwood which makes it suitable for structural applications.

- The carrying capacity of the composite material are higher when compared to the use of timber
- The composite material can prevent against wrot, fire and decay

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