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Structural behavior of ferrocement beams under flexure load

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ABSTRACT

Considerable attention has been given to the advancement of ferrocement concrete beams. In 12 ferrocement beams, conventional bar reinforcing and two types of mesh were employed in place of stirrups, and the beams were tested with simple support under a centrally concentrated load. It is discussed how various reinforcing methods affect failure loads and the structural response. The utilization of mild steel bars in combination with welded metal mesh in two or three layers results in higher moment than using only welded metal mesh without upper steel bars, regardless of the specific type of welded metal mesh used. Also Flexural strength was much improved when reinforcing ferrocement beams using fiberglass steel mesh and mild steel bars instead of just mild steel stirrups. Finally we can say that mild steel reinforced with welded metal mesh exhibited the most favorable structural performanceFerrocement beams exhibited superior crack control and avoided spalling in contrast to traditional beams. Among the specimens reinforced with fiberglass mesh, those had the lowest occurrence of spalling compared to beams reinforced with welded metal mesh. One practical alternative to traditional reinforced concrete beams is thin ferrocement forms, which have several advantages and are expected to have positive effects on the environment and the economy in both developed and developing nations.

Keywords: Ferrocement beams, Mesh reinforcement, Flexure load

1. Introduction

Ferrocement as a structural idea has showed good mechanical properties, including toughness, impact resistance, and fracture control. These capabilities are accomplished by equally dispersing reinforcement inside the matrix at near intervals. One major feature of ferrocement material is its comparatively low cost per unit. However, in nations with greater labor costs, the utilization of ferrocement becomes economically impractical [1]. In places where low-priced, unskilled labor is readily available and can be trained, and if a standardized building method is followed, labor efficiency will greatly increase, leading to a decrease in the cost per unit. In such instances, ferrocement appears as a more suitable choice compared to other construction materials, which are much more expensive and involve a greater level of specialist expertise. Ferrocement manufacture has mostly been applied for roofs, shell buildings, water tanks, and predominantly boats. In an ACI state-of-the-art research [2] on ferrocement, ferrocement is defined as a type of thinwalled reinforced concrete panel commonly made in hydraulic cement mortar reinforced with closely spaced layers of continuous and very tiny size wire mesh. The mesh might be comprised of steel or other suitable materials. The mortar matrix's quality and alignment should be appropriate for the mesh and framework systems that it is designed to summarize. The matrix may have uneven filaments. In addition to producing a watertight structural element that will shield the steel from abrasion and erosion, they will offer appropriate protection against corrosion for the steel. Water seepage and direct chemical attack on the reinforcement are two potential repercussions of classic and conventional ferrocement building technologies. Both of these potential problems are surmountable with basic improvements that are simply adopted in any nation. To begin, grouping reinforcing meshes and linking them to skeleton bars generates a robust cage that streamlines construction, boosts its efficacy and economy, and, most significantly, assists the mesh in finding its best placement and coverage. The key materials utilized in Ferrocement construction include frame rods, reinforced rods, reinforced mesh, clips and fastening wire, admixtures, water, sand, bonding rod, jointing chemicals, and cement. Ferrocement construction is highly appealing in numerous developing nations due to the widespread availability of basic raw materials, the ability to fabricate it into various desired shapes, the utilization of low-skilled labor, the ease of construction, its lightweight nature, long lifespan, retrofitting capabilities, low cost of construction materials, and its excellent resistance to earthquakes.

Additionally, fibers are employed to mitigate the occurrence of cracks caused by drying shrinkage and thermal expansion/contraction, to reduce concrete permeability, to enhance impact resistance, shatter resistance, and abrasion resistance, while imparting toughness and residual strength through fibrillation. Water seepage and direct chemical attack on the reinforcement are two potential repercussions of classic and conventional ferrocement building technologies. Both of these potential problems are surmountable with basic improvements that are simply adopted in any nation. First off, building a strong cage by grouping reinforcing meshes and anchoring them to skeletal bars helps streamline construction, boost its efficiency and economy, and, most significantly, enable the mesh find its optimal location and cover. When some or all of these essential ideas are implemented, new advances in ferrocement construction and application—such as in the restoration and rehabilitation of sewers and tunnels—are developed. [3] as well as the construction of composite sandwich slabs. [4] The fabrication of ferrocement beams with high static and dynamic strength, durability, and crack resistance—suitable for both typical and unusual applications—is the extension of these advances in this study.

2. Experimental Details

This study evaluated the flexural behavior of reinforced ferrocement concrete beams that were strengthened using different types of reinforcing materials. Twelve ferrocement beams, with dimensions of 1000 X 100 X 50 mm, were created according to the standards stated in the Egyptian Code Practices (E.C.P. 203/2007) for design, mixing, and curing processes [5]. The structure is strengthened by adding various steel reinforcement elements, including polypropylene mesh, steel bars, and welded galvanized steel mesh. The essential components were the amount of steel bars and steel mesh positioned at the upper and lower regions of the beams. Within this program, we conducted experiments to assess the response of the objects when subjected to flexural strain.

2.1. Used materials

The Ordinary Portland cement used was made at the Suez cement factory. E.S.S. 4657-1/2009, the Egyptian Standard Specification, was met by the material's physical and chemical qualities [6]. For this experiment, fine siliceous sand was used. E.C.P. 203/2007 [5], E.S.S. 1109/2008 [7], and ASTM C 33, 2003 [8] are all standards that the product's features adhere to. Its modulus of fineness is 2.7 and specific gravity is 2.6 t/m3, which prove that it is very pure and free of impurities, grading is shown in figure (1). High Range Water Reducer (HRWR) was the name of the superplasticizer that was used. The combination's workability was improved by its employment. Sika Group manufactured and marketed the admixture under the ASTM (Sika viscocrete 20) brand name. This product meets all of the requirements stated in reference [9] for Sika viscocrete 20 and ASTM C494 types A and F. At room temperature, the brown liquid admixture has a density of 1.18 kg/liter. The HRWR made up 2.0% of the cement by weight. Polypropylene fibers (PP 300-e3) were utilized. You might find it in Egyptian marketplaces. It was added to concrete mixes to create a reinforced concrete jacket, which enhanced the concrete's characteristics. Following the manufacturer's instructions, we determined the addition percentage to be 900g/m3. Polypropylene Fibers 300-e3's physical and chemical characteristics are displayed in Figure 2-a and Table 1. Using pure, drinkable water, the plates are solidified and hardened in accordance with Egyptian Code Practices (E.C.P. 203/2007). Ezz Al Dekhila Steel of Alexandria produced the reinforcing steel bar that was used. The material's physical and chemical characteristics meet the requirements of the Egyptian Standard Specification (E.S.S. 262/2011). Steel bars measuring 6 millimeters were used to reinforce the ferrocement plates. The yield stress was

240 MPa and the tensile strength was 350 MPa for the steel bars. Metal mesh that had been soldered onto ferrocement plates served to reinforce them. The substance's physical and chemical properties are up to par with what is required by the Egyptian Standard Specification (E.S.S. 262/2011). [2]. Please, see Figure 2-b and Table 2. The Italian firm Gavazzi Company supplied the fiberglass mesh. Fiberglass mesh was used to reinforce concrete beams. The technical parameters of fiberglass mesh are listed in Table (3) by the producing business. Here is a graphic illustration of the fiberglass mesh in Figure (2-c).

2.2 Mortar Matrix

The ultimate compressive strength of the concrete mortar used to cast the plates was supposed to be 350 kg/cm^2 and 35 MPa at 28 days of age. The Egyptian Code Practices (E.C.P. 203/2007) [5] and the ACI committee 549 report (2008) [1] were the sources used to determine the mix parameters for the mortar matrix. The volume of the combined components was determined to be within this range for every mix, which was made using a mechanical mixer in the lab with a 0.05 m3 capacity. Prior to adding the mix water and re-mixing the entire patch in the mixer, the component ingredients were first dry mixed. Every specimen was subjected to manual compaction. Table (4) offers blend attributes by weight for each of the groupings.

2.3 Preparation and Casting of Test Specimens

Figure (4) depicts the flow chart for the experimental program that was carried out. Figure (3) and Tables (5) provide a description of the ferrocement beams utilized in the flexure test as well as information on the reinforcement and plate dimensions. Before casting concrete mortar, thin oil was added to the wooden forms used to manufacture the plates [11-16]. After that, the reinforcement was inserted correctly in the forms. After that, the concrete was poured into the molds, and the vibrating table was utilized to fully compact it. The trowel was used to level the concrete's surface inside the molds once they had been filled with the material. Under laboratory settings, beams were raised into the forms and covered with polythene sheets for a full day, until the sides of the forms were removed. Beams were remolded, and then they were submerged in water for 28 days shortly before testing, after the cure of 28 days. Before testing, the beams were held in the laboratory for four hours.

3. Discussion

The findings and conclusions of tests done looking into the efficacy of using welded metal mesh, and fiberglass mesh in reinforcing ferro cement beams are presented in the results and comments of the experimental program. The ultimate loads and cracking patterns of beams reinforced with this mesh and those strengthened with standard steel bars were examined in the study. Based on the three criteria taken into consideration in this experimental investigation—the kind of steel reinforcement, the number of layers, and the kind of mesh used—comparisons are made. These parameters' relevance on the structural responses was studied.

The results and discussions of the experimental program, covers the results of experiments carried-out to explore the effectiveness of using the welded metal mesh and fiberglass mesh in reinforcing ferrocement Beams. The study included a comparison between the ultimate loads, and cracking patterns of beams reinforced using this mesh and those reinforced with conventional steel bars, Comparisons are conducted based on the three parameters considered in this experimental investigation; type of steel reinforcement, number of layers and type of used mesh. The effect of these characteristics was explored on the structural responses.

The ultimate load was researched, and the test specimen could sustain (Pu), the corresponding ultimate moment (Mu), Stress (σ) determined from the basic relations: -

$$Mu = Pu\ L/4, \quad \sigma = Mu*Y/I$$

Where: - L is the clear span length, I is the inertia of cross section and Y = h/2

Figures and Tables

Table (1) Physical and Mechanical Properties of Polypropylene Fibers 300-e3

Length	Various
Type / Shape	Graded / Fibrillated
Absorption	Nil
Specific Gravity	0.91
Electrical Conductivity	Low
Acid &Salt Resistance	High
Melt Point	ºC(324º)162
Ignition Point	593 ºC(1100ºF)
Thermal Conductivity	Low
Alkali Resistance	Alkali Proof

Table (2) Mechanical properties of welded metal mesh

Dimensions	12.5mm× 12.5mm
Weight	463 g/m2
Yield Stress (N/mm2)	350
Ultimate Strength (N/mm2)	550
Modulus of Elasticity (KN/mm2)	170

Table (3) Technical specifications of fiberglass mesh

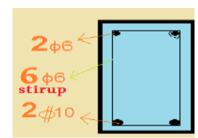
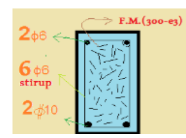
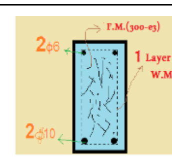
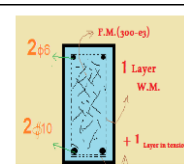
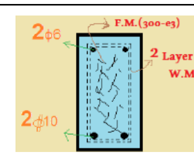
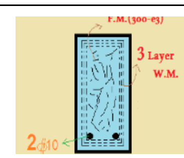
Size		12.5 × 11.5 mm
The dimensions of fiber strings	Longitudinal directions	1.66 × 0.66 mm
	Transverse direction	1 × 0.5 mm
Weight		123 g/m2
Volume fraction		0.535 %
Tensile strength		325 N/mm2
Elongation in longitudinal		55%

Table (4): Constituents of mortar used per m^3

Mix Design	Mix. Weight (kg/ m3)

Cement	350
Sand	870
Water	157.5
S.P.	7.0
Fibers	0.9

Table (5) Shows the experimental program of all series of the plates.

Series	Beam No.	Type of RFMT	No. of layers of Reinforcement	
A	A1	Steel bars	Steel bars (2 Φ 6) top (2 ϕ 10) bottom Stirrups 6ϕ 6. / Without fiber glass	
	A2	Steel bars	Steel bars (2 Φ 6) top (2 ϕ 10) bottom Stirrups 6ϕ 6 With fiber glass	
B	B1	Welded mesh and steel bar	Steel bars (2 Φ 6) top (2 ϕ 10) bottom One layer of welded steel mesh	
	B2	Welded mesh and steel bar	Steel bars (2 Φ 6) top (2 ϕ 10) bottom One layer of welded steel mesh + one layer in tension	
	B3	Welded mesh and steel bar	Steel bars (2 Φ 6) top (2 ϕ 10) bottom two layers of welded steel mesh	
	B4	Welded mesh and steel bar	Steel bars (2 Φ 6) top (2 ϕ 10) bottom three layers of welded steel mesh	

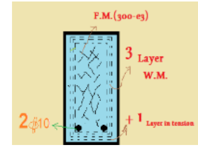
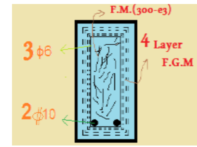
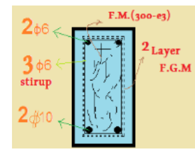
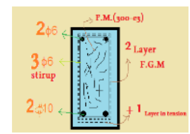
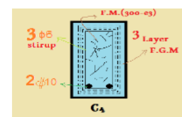
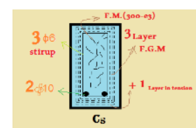
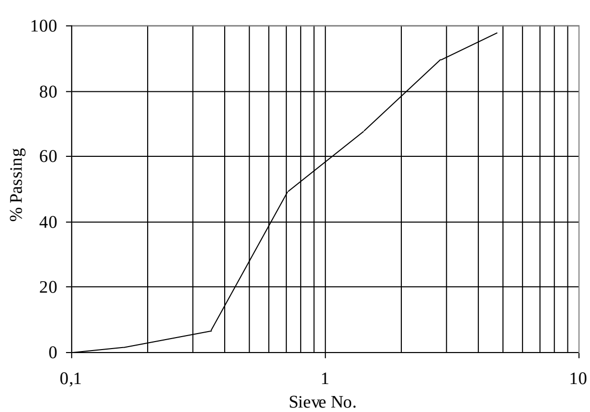
	B5	Welded mesh and steel bar	Steel bars (2 Φ 6) top (2 ϕ 10) bottom three layers of welded steel mesh+ one layer in tension	
C	C1	Fiberglass mesh and steel bar	Steel bars (2 ϕ 10) bottom four layers of fiberglass mesh + 3 Φ6 stirrups	
	C2	Fiberglass mesh and steel bar	Steel bars (2 Φ 6) top (2 ϕ 10) bottom two layers of fiberglass mesh	
	C3	Fiberglass mesh and steel bar	Steel bars (2 Φ 6) top (2 ϕ 10) bottom two layers of fiberglass mesh + one layer in tension + 3 Φ6 stirrups	
	C4	Fiberglass mesh and steel bar	Steel bars (2 ϕ 10) bottom three layers of fiberglass mesh + 3 Φ6 stirrups	
	C5	Fiberglass mesh and steel bar	Steel bars (2 ϕ 10) bottom three layers of fiberglass mesh + one layer in tension + 3 Φ6 stirrups	

Figure (1) Grading of the Sand Used.





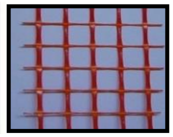


Fig.(2-a) Polypropylene Fibers 300-e3

Fig.(2-b) Welded Metal Mesh

Fig.(2-c) Fiberglass Mesh

Fig.(3) Mold ready for casting

Fig(4) casting beams

Fig(5) Flexure test setup

4. Results

As shown in the table (6) and figure (6),The utilization of (one-two-three) layers of welded metal mesh in reinforcing ferrocement beams, as depicted in the figure, significantly improves their flexural strength compared to the use of skeleton steel bars. Additionally, by incorporating two, three, or four layers of welded metal mesh into the reinforcement of ferrocement beams, the moment capacity is significantly increased compared to employing only skeletal steel bars. The addition of more steel mesh layers in ferrocement beams results in an increase in the first crack load, ultimate load, and moment.

Fig (6) Bending moment test results of 12 beams

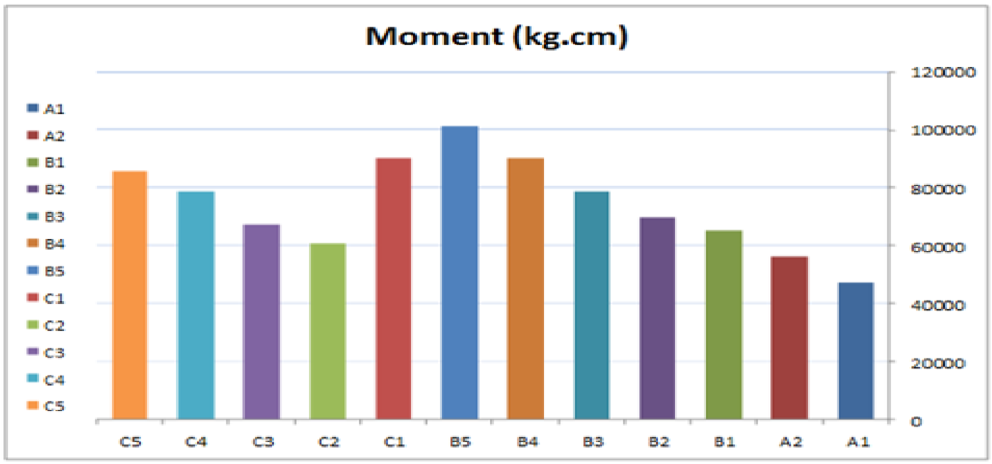


Table (6) Test result of ferrocement beams

Group	Beam	P (Ton)	M (Ton.cm)	σ (Ton/cm^2)
A	A1	2.1	47.25	0.567
	A2	2.5	56.25	675
B	B1	2.9	65.25	783
	B2	3.1	69.75	837
	B3	3.5	78.75	945
	B4	4.0	90.0	1080
	B5	4.5	101.25	1215
C	C1	4.0	90.0	1080
	C2	2.7	60.75	721.8
	C3	3.0	67.5	810
	C4	3.5	78.75	945
	C5	3.8	85.5	1026

5 -Conclusion

1 - The introduction of synthetic fibers in the mortar mix boosted the first crack load, ultimate load, and moment, irrespective of the type of reinforcing mesh applied in ferrocement laminates.
2 - Synthetic fibers were applied to postpone the occurrence of the initial fracture and promote the spread of fractures in ferrocement beams. This improved the rigidity of the test specimen.
3 - Specimens incorporating ferrocement beams reinforced with expanded wire mesh exhibited superior initial crack load, ultimate load, and energy absorption in comparison to specimens reinforced with welded steel mesh, irrespective of the presence of synthetic fibers.
4 - The flexural strength of ferrocement beams is significantly enhanced by including welded steel mesh along with mild steel bars in their reinforcement, as opposed to relying just on mild steel bars. This phenomenon may be attributed to the ability of welded steel mesh to effectively control the formation of cracks.
5- Flexural strength was much improved when reinforcing ferrocement beams using expanded steel mesh and mild steel bars instead of just mild steel bars.
6- Ferrocement beams demonstrated superior crack control and reduced spalling when compared to conventional beams. This improvement can be attributed to the increased reinforcement provided by multiple layers of mesh in the ferrocement beams, which effectively controlled the width of cracks.

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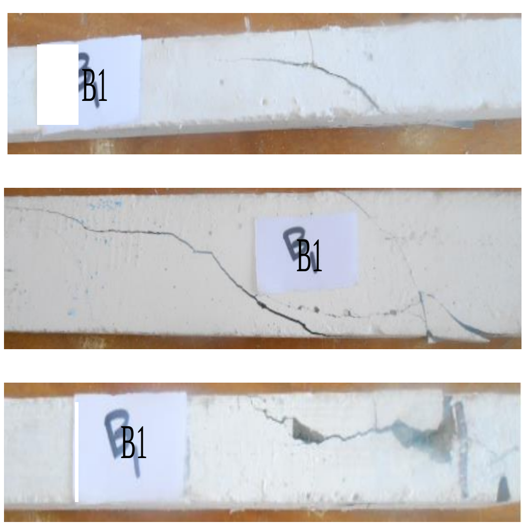
Crack Pattern

A_1

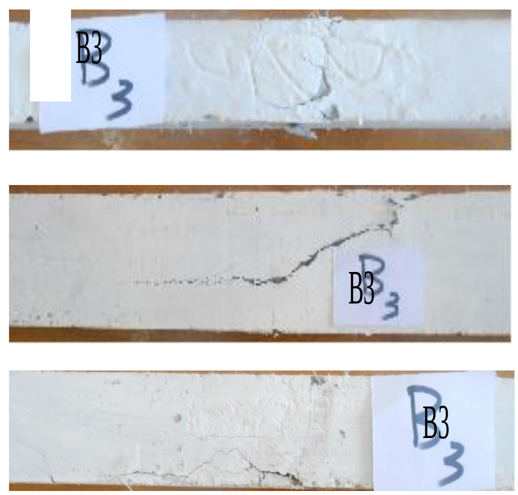
A_2

B_1

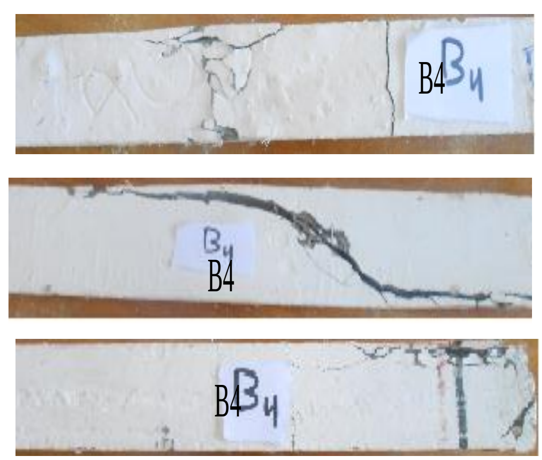


B_2

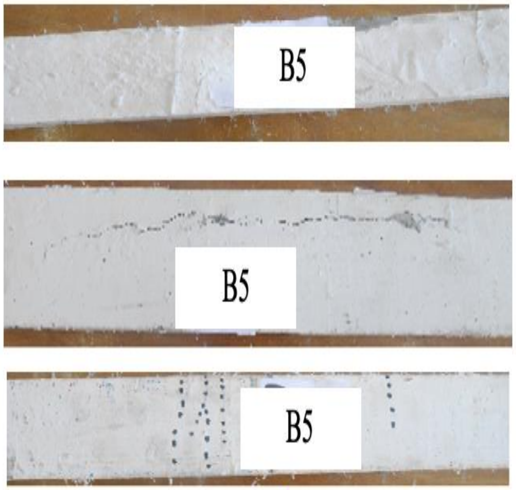
B_3



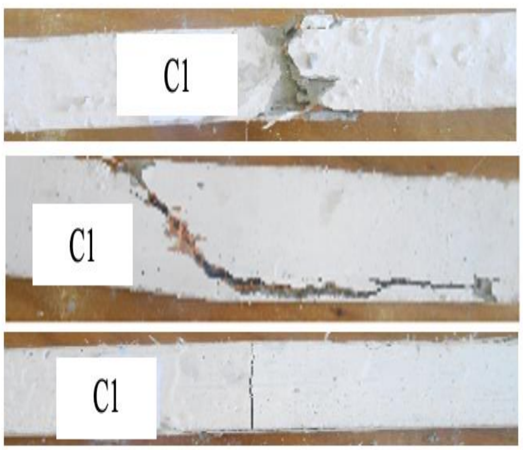
B_4



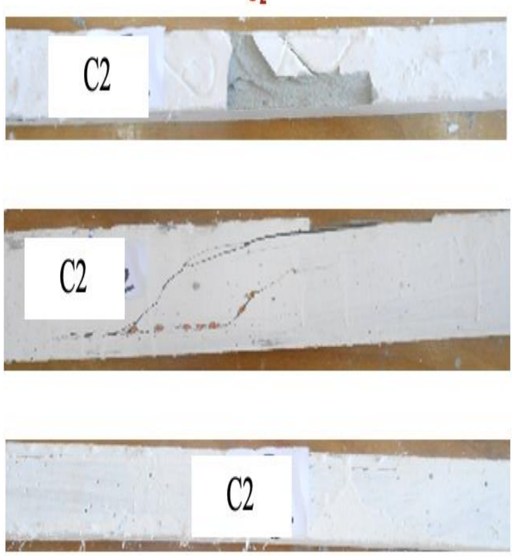
B_5



C_1



C_2



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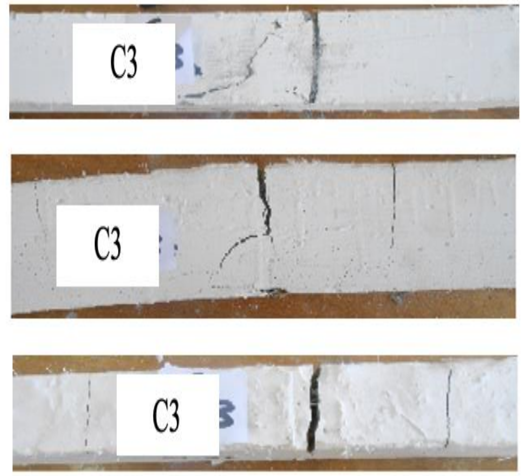
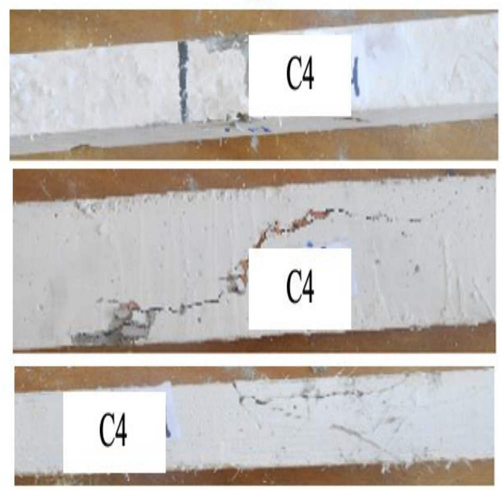


C_4



C_5