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A Comparative Study on Punching Shear Strength Statistics for Ferrocement Slabs

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Abstract

Ferrocement is a modern material that is considered composite as it is made of cement mortar and tightly packed layers of wire mesh. Recent ferrocement applications include prefabricated rooftop elements, load-bearing panels, and bridge slabs. However, in various parts of the world, particularly the eastern hemisphere, numerous individuals and research groups have made significant efforts to study the engineering of ferrocement which includes tensile, compressive, impact, and fatigue strength, as well as, cracking behaviour. Despite this, the shear strength of ferrocement slabs has received scant consideration. However, since ferrocement is increasingly used in structural applications, transverse shear has become a determining design factor. This paper presents the behavior of ferrocement slabs when subjected to punching shear. Eleven square slabs with dimensions 916 mm were cast, and their thicknesses were adjusted along with the wire mesh and mortar strength. After 14 days of curing, these slabs were removed from the water tank, de-moulded, and tested. Prior to testing, the top surface of these slabs was bleached to reveal the crack pattern clearly. The slabs failed in punching instead of flexural failure and they demonstrated ductile behaviour. A comparison for the observed results for the strengths and behavior of the slabs was made.

Keywords: Ferrocement; Punching shear; Slabs; Comparison; Failure mode

1 Introduction

Ferrocement has been employed in a variety of applications during the last two decades, including strengthening and repairing existing reinforced concrete, steel, and concrete water tanks, sewers, and swimming pools, as well as seismic retrofitting masonry walls. Ferrocement coatings are relatively lightweight and, in the majority of cases, relatively simple to install. The reinforced material's homogenous distribution and high surface area to volume ratio result in a more effective fracture arrest mechanism, i.e., crack propagation is halted, resulting in the material's high tensile strength. The ultimate tensile resistance in Ferrocement is achieved by applying the reinforcement in the loading direction. Nevertheless, analysing and designing ferrocement members are quite complex and basically follows the principles of reinforced concrete elements specifically in flexure and shear. In comparison to studies on the flexural behaviour of ferrocement elements, very few research publications exist on the shear behaviour of ferrocement elements. This could be because these elements have a very high span-to-depth ratio. Due to the scarcity of raw resources and the demand for low-level technical capabilities, ferrocement has a high potential for contraction in developing nations (ACI, 1997). Although ferrocement materials are typically thin and frail, they are equally robust and aesthetically pleasing and offer a diverse range of construction solutions, particularly for roofing and wall construction (Pushyamitra, 2011).

When ferrocement was used to examine the wear of concrete boxes, it resulted in a considerable improvement in stiffness, strength, and ductility (Abdullah & katsuki, 2002). Ferrocement is a coating that improves the shear strength of brickworks (Walker & Damu, 1997). Structural units formed of ferro cement planes can be used with confidence in a variety of applications such as low-cost housing plans, agriculture, and industrial use (Akhthar ET.AL, 1999). For the same steel stress, the fracture widths in ferrocement are orders of magnitude smaller than those in reinforced concrete, making it a superior material for water retention structures and suggested for the construction of water tanks (Balaguru ET.AL, 1997) and (Naaman, 1971). The failure modes and crack patterns of ferrocement box beams subjected to two-point stress tests show that the smaller the span to effective depth ratio, i.e., a/d1, the more pronounced the diagonal tension failure; if the ratio is greater than one, the beam tends to fail flexibly (Abdul Samad ET.AL, 1998). Another study looked at the location of diagonal cracks in rectangular reinforced concrete beams. The location of the crucial diagonal fracture as measured from the nearest support increases as the a/d ratio grows and, to a lesser extent, as 'fcu' decreases (Al-kubaisy & Nedwell, 1998). The ultimate moment and the behavior of ferrocement in flexure increase with increasing matrix grade and reinforcement volume fraction (Mansur & Paramasivam, 1986). Shear strength of ferrocement beams subjected to transverse shear with varied reinforcing volume percentages was found to be dependent on mortar, wire mesh strength, volume %, and shear span (Venkata & Basa, 1988). The punching shear capacities of the retrofitted test specimens were significantly higher than those of the bare specimens with apertures, and most structural code equations grossly underestimate the punching shear capacities of the test specimens (Durucan & Anil, 2015). There have been few studies into ferrocement members' behavior under punching shear (Tan, 1994; Al-Kubaisy & Jumaatco, 1999).

There is currently no code formula for the shear strength of ferro cement elements. There is a necessity to demonstrate that the shear strength equations supplied by existing norms of practice for reinforced concrete may also be applied to ferrocement. All samples of slabs A1, A2, A3, A4, and A5 were similar in dimensions except reinforcement, i.e., wire mesh and varying skeleton steel, volume fraction of reinforcement (vf). Slabs B1, B2, and B3 were developed to investigate the influence of slab thickness (h), using 20-, 25-, and 35-mm slab thicknesses. Slabs C1, C2, and C3 are composed of three identical slabs with varying compressive strengths of mortar (fcu). The load-deflection relationship is investigated, as well as the punching shear behaviour.

2 Materials and Methods

Cement, sand, water, superplasticizer, wire meshes, and skeletal steel were used in this experimental work. Throughout the experiment, ordinary Portland cement (OPC-43 grade) was employed. As a fine aggregate, well-graded locally accessible river sand down to 2.36 mm in size was used. Wire mesh is a significant component of ferrocement and is often composed of fine wires. As shown in Figure 1, the wire mesh is 1 mm in diameter and has 12.5 mm x 12.5 mm openings. The wire mesh has a yield strength of 390 N/mm^2 in tension.

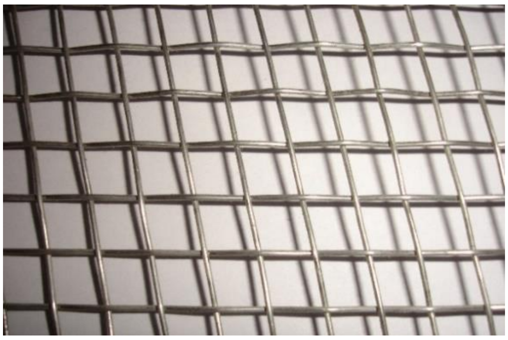

Fig. 1: Square wire mesh

Between the upper and lower layers of the wire mesh, skeletal steel bars 6 mm in diameter are symmetrically positioned in two orientations. Steel bars have yield strength of 430 N/mm2. The strength of the mortar was increased by changing the water-cement ratio and adding suitable admixtures to improve workability and speed-strength development. To aid in crack detection, the slabs' bottom and top faces were whitewashed. Table 1 contains information about the various specimens cast.

Table 1: Details of test specimens

Slab Notation	**Investigated parameter**	**Thickness of slab h (mm)**	**No. of layers of wire mesh**	**No. of skeletal steel**	**Volume Fraction of Reinforcement V_f (%)**	**Mortar Strength (N/mm^2)**
A1	V_f	30	2	10	1.45	40
A2		30	2	8	1.24	40
A3		30	1	8	1.03	40
A4		30	3	8	1.45	40
A5		30	2	-	0.42	40
B1	h	20	1	10	1.85	40
B2		25	2	9	1.85	40
B3		35	2	10	1.85	40
C1	f_{cu}	30	2	6	1.04	30
C2		30	2	6	1.04	20
C3		30	2	6	1.04	12

As seen in Figure 2, all specimens were exposed to a single concentrated force delivered through the centre of a rigid steel loading plate using a hydraulic jack.

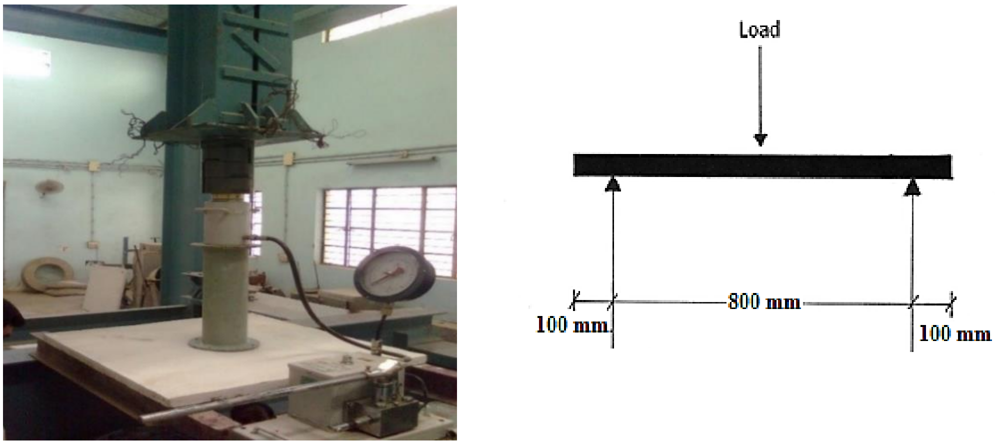

Fig. 2: Loading set up for the experimental work

By using the hydraulic jack, the load is gradually increased. The deflection under the load point was determined using a dial gauge attachment (the least count is 0.01mm). The load was applied in about 2 kN increments. Following each load increase, the dial gauge reading was collected, and the area examined for the presence of cracks.

3 The Behavior of Slabs

In general, it was observed that, the load-deflection relationship is linear until the slab begins to crack. The first crack began at around 20%–35% of each slab's ultimate shear strength on the tension side of the slab beneath the loaded area and progressed radically across the slab to the sides.

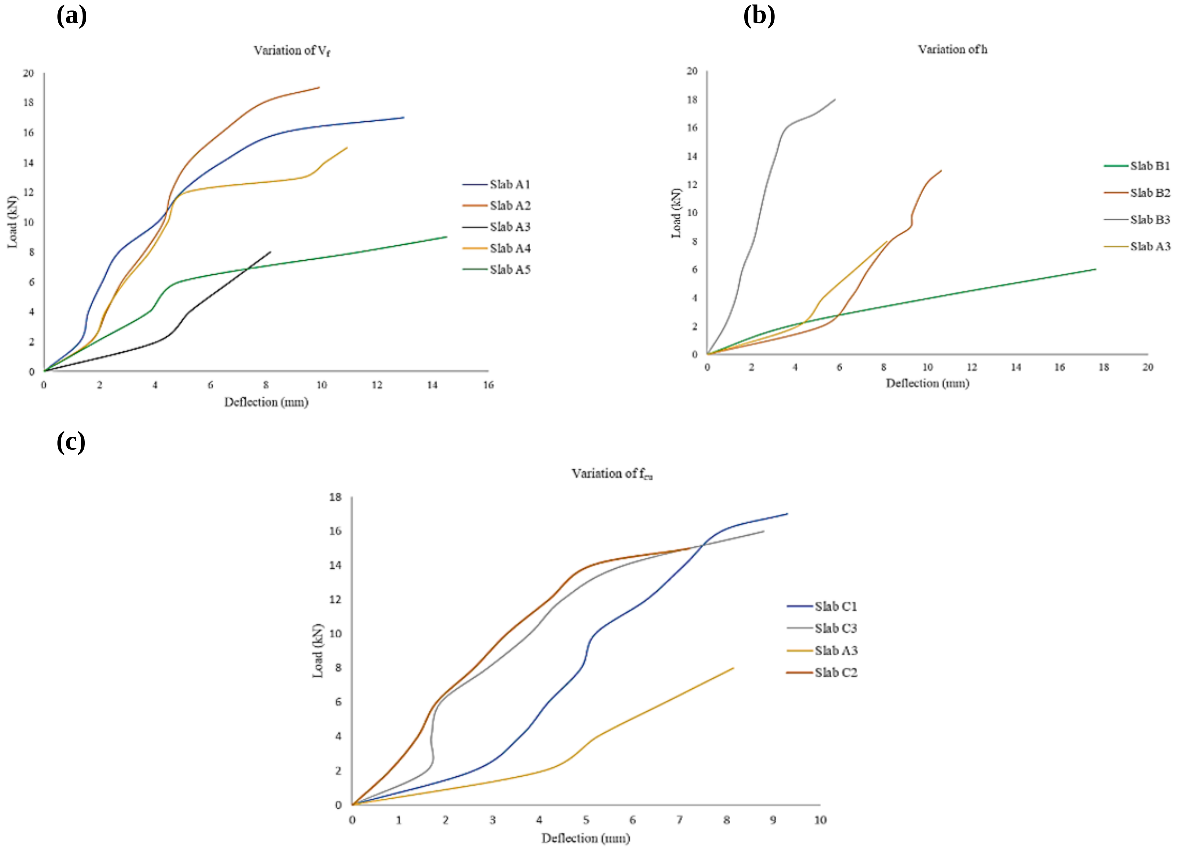

Fig. 3: Load-Deflection curves

(a) Variation of V_f **(b)** Variation of h **(c)** Variation of f_{cu}

When a slab cracks, its stiffness is reduced, and the load picks up once the fracture development has stabilized with insignificant slab deflection. As the ultimate load approaches, the stiffness of the curve is reduced further until it is almost horizontal. On the slab's top face, punching shear failure was evident, but on the slabs bottom face, just an outline of the truncated failure cone with a substantially larger diameter was created, along with the noticeable lifting of the slab's corners. When the ultimate load is attained, the load-carrying capacity suddenly decreases, and the slab fails in punching shear. Following the ultimate load, the load-bearing capacity is entirely determined by steel reinforcement and membrane action.

4 Failure Pattern in Slabs

Also in the slabs, radial cracks were observed on the bottom face, primarily between the loading point and the edges of the panel; on the upper surfaces, a circular punching effect of the loading area, as can be seen on the surface in Figure 4. It was mirrored on the bottom face with an enlarged picture, clearly indicating the truncated cone. Although this overall pattern of cracking is constant across all slabs, depending on the test parameter, variances in the number and spacing of cracks, as well as the perimeter of the bottom failure cone, were noted. Around 40% to 50% of the ultimate load results in the formation of new cracks between the supports and at the loading site. Increased load exacerbated the cracks and brought them to the ultimate load point. Observation demonstrates that as the thickness (h) is raised, the bottom perimeter increases. Although the overall pattern of cracking is essentially comparable for the variations in f_{cu} and h.

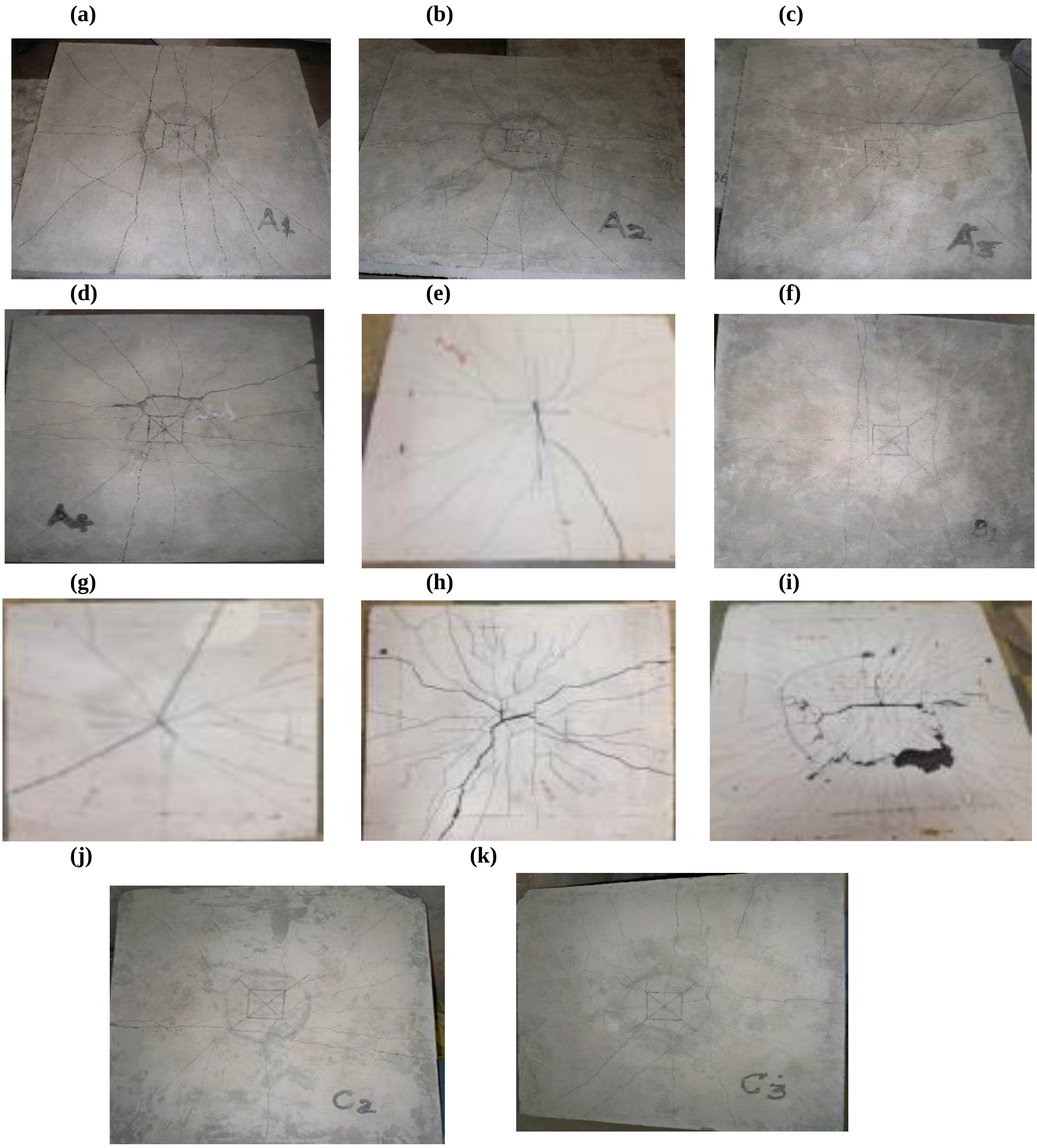

Fig.4: Cracked pattern and punching shear envelope for different slab

V_f has a major influence on the distribution of cracks. Increased reinforcement resulted in fewer larger fractures and more closely spaced cracks. Cracks were clustered near the loading point at exceptionally high V_f values, with the majority developing along the reinforcing grid lines. Most specimens tested failed in punching shear. Based on the experimental data, the critical perimeter on the slab's top surface typically occurred quite close to the plate's face. While the matrix bulged out towards the bottom of the slab, this frequently resulted in a much larger perimeter than at the top. Additionally, the essential perimeter's size and form are consistent. This indicated that the shear plane generated was angled at an angle, resulting in the pyramidal or conical shape associated with the punching shear failure.

5 Conclusion

All the slabs were subjected to single concentrated load delivered using a hydraulic jack. It was observed that instead of flexure, the ferrocement slabs failed due to punching shear failure. On the top surface, the inclined shear plane typically originates near the periphery of the loaded area, with fewer cracks on the top surface than on the bottom. The load-deflection trend of the ferrocement slabs subjected to punching shear exhibits two peaks and demonstrated ductile behaviour. The first peak is caused by punching shear failure, whereas the second peak is caused by the development of tensile membrane action in response to high deformation. The second peak is often greater than the first in slabs with a high-volume proportion of reinforcement or a larger loaded area. In terms of stress, both cracking and punching shear strengths rise independently of V_f, f_{cu}, and h, but decrease as effective span increases. Punching shear strength has increased up to 1.04 percent of the volume percentage of reinforcement (V_f) and an additional increase in (V_f) resulted in a decrease in punching shear strength. Increases in slab thickness (h) resulted in an increase in punching shear strength while increased Mortar strength (f_{cu}) results in increased punching shear strength. The research parameters do not affect the number and extent of cracks that occur on the compression side. Ferrocement elements shear behaviour is almost identically to reinforced concrete elements.

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