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UTILIZATION OF FERROCEMENT AND ZINC PLATE AS FLOOR PLATE FORMWORK OF MULTI-STOREY HOUSES

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Abstract

Ferrocement is a thin-walled concrete that is less commonly used than reinforced concrete. On the other hand, zinc plate is a type of metal frequently utilized as roofing material and for rain gutters. This study aimed to evaluate the tensile strength of zinc and the flexural strength of ferrocement to ensure their safe load-bearing capacity for multi-storey building floors. The study was conducted experimentally by testing the strength of formwork plates made from ferrocement, with a base plate comprising a layer of zinc. The ferrocement used in the experiment contained two layers of wire mesh and mortar with a cement-to-sand ratio of 1:3. The experimental results yielded a formwork flexural strength value of 0.403 kNm, mortar compressive strength of 22.3 MPa and zinc yield stress of 194.6 MPa. Based on construction trial activities in multi-storey houses, zinc-coated ferrocement plates are deemed safe for application as permanent formwork for floor slabs.

Keywords: Ferrocement, Formwork, Mortar, Plate, Zinc.

1. Introduction

Floor slabs in multi-storey buildings are commonly constructed using traditional reinforced concrete. This method involves using formwork, which is removed once the concrete attains its characteristic strength. Innovative floor slab technologies have been developed to improve construction efficiency, eliminating the need for formwork dismantling. Notable examples include bonded plates and hollow precast concrete plates, both widely used in modern construction.

Bondek plates, manufactured from high-quality steel, serve as permanent formwork and significantly reduce the required volume of floor slab reinforcement. Bondek plates necessitate high-quality concrete casting despite these advantages which improves time efficiency. They are also relatively more expensive than conventional concrete slabs [1]. In contrast, hollow precast concrete plates are prefabricated in factories with prestressed reinforcement. This technology eliminates the need for on-site concrete casting unless additional reinforcement is required to enhance the shear stability of the floor structure. Hollow precast concrete plates offer substantial time efficiency [2, 3], although their costs remain relatively high.

At first glance, Bondek plates resemble zinc sheets, particularly when the zinc sheets are enhanced with embossed protrusions and connectors. This similarity has prompted questions about the feasibility of using modified zinc sheets as a substitute for Bondek plates. Similarly, hollow precast concrete slab technology is conceptually analogous to the concrete slabs used as gutter covers in residential areas. These gutter covers are typically fabricated near the installation site using moulds of specified dimensions. Once cured, the slabs are manually positioned over the gutters to create a durable cover supporting vehicular traffic. This practical approach has raised questions about the potential adaptation of gutter cover slabs as precast floor slabs for multi-storey buildings.

Based on current technologies for constructing floor slabs, this study investigates an alternative method for multi-storey buildings that employ ferrocement and zinc-coated plates as the base. The zinc-coated ferrocement plates are intended to function similarly to Bondek or hollow precast concrete plates. These plates are lightweight because they are fabricated 4-5 cm thick, enabling easy manual handling. During implementation, the zinc-coated ferrocement plates act as permanent formwork, reducing the need for additional concrete and steel reinforcement in floor slabs. This approach aims to achieve a more economical solution than conventional slab construction methods.

Ferrocement is a thin-walled concrete construction composed of hydraulic cement reinforced with a mesh of relatively small diameter [4]. The mesh, which may consist of metal or other suitable materials, is applied in continuous layers. Although ferrocement has seen significant use in Indonesia, it remains less common than reinforced concrete. Unlike reinforced concrete, ferrocement does not incorporate gravel or traditional reinforcing steel. As shown in Fig. 1, ferrocement utilizes a mortar mixture combined with multiple layers of wire mesh, such as the widely recognized chicken wire mesh.

This study investigates the tensile strength of zinc and the flexural strength of ferrocement to ensure their load-bearing capacity for use in multi-storey building floors. Additionally, the research explores the application of zinc-coated ferrocement plates as a practical alternative to existing floor slab technologies, such as bonded plates and hollow precast concrete plates.

Fig. 1. Mortar and wire mesh as ferrocement components.

Previous studies have examined using zinc-coated ferrocement plates as floor slab materials in multi-storey buildings [5]. Similar research has evaluated the flexural strength of aluminium-coated ferrocement plates, demonstrating optimal results with a mortar mix ratio of 1 part cement to 3 parts sand [6]. The ductility of ferrocement plates can be enhanced when applied in curved forms [7], and mixing copper slag into the mortar has shown improvements in both flexural strength as well as ductility [8]. As one of the earliest forms of reinforced concrete [9], ferrocement's flexural strength is significantly influenced by the number of carbon fibre mesh layers incorporated.

Advancements in ferrocement technology have led to the development of sandwich ferrocement, which aims to reduce the material's self-weight [10]. Beyond plates, ferrocement has been successfully applied to beam structural components [9, 11-13] and column structural components [14, 15], demonstrating its versatility in various structural applications.

2. Research Method

The research methodology began with a comprehensive literature review of previous studies on the use of ferrocement and zinc as construction materials. Subsequently, both primary and secondary data were collected to evaluate the potential of zinc-coated ferrocement plates as an alternative formwork for constructing floor slabs in multi-storey buildings. Primary data were derived from experimental tests assessing the tensile strength of zinc plates, the compressive strength of mortar, and the flexural strength of zinc-coated ferrocement. Secondary data were obtained from analytical results based on material mechanics theories, using parameters derived from the experimental outcomes. The study culminated in developing a design drawing for zinc-coated ferrocement, which was tested as a formwork for floor slabs in multi-storey residential buildings. A visual representation of the research flow is shown in Fig. 2.

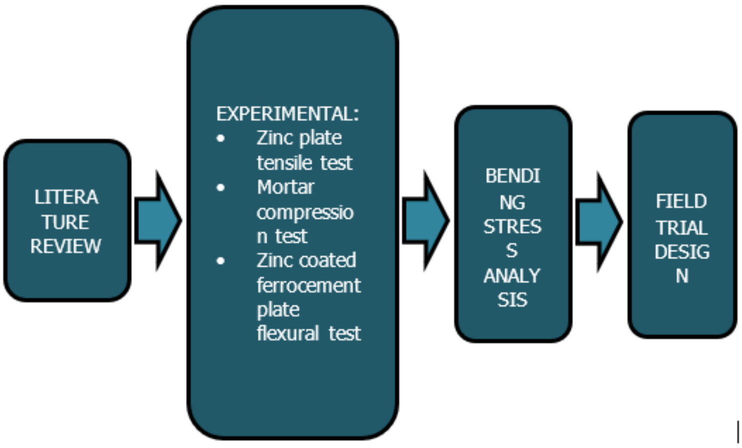


Fig. 2. Research flow chart.

2.1. Zinc plate tensile strength

The zinc plate utilized in this study is a galvalume zinc plate commonly used for manufacturing rainwater gutters. This zinc (Zn) plate is readily available at hardware stores and is cost-effective. The gutter zinc plate has a thickness of 0.2 mm and a width of 55 cm, as shown in Fig. 3. Since the material is typically intended for gutter applications, its tensile strength is not specified by the manufacturer, necessitating a separate tensile test to determine its yield stress and elastic modulus.

Tensile test specimens were prepared following ASTM standards, with dimensions shown in Figs. 3 and 4. Four specimens were fabricated, one of which is shown in Fig. 5. Additionally, the test setup and instrumentation used for the tensile testing are shown in Fig. 6.

Fig. 3. 0.2 mm galvalume zinc plate.

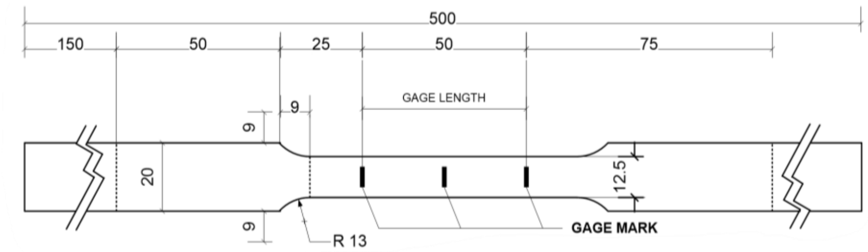
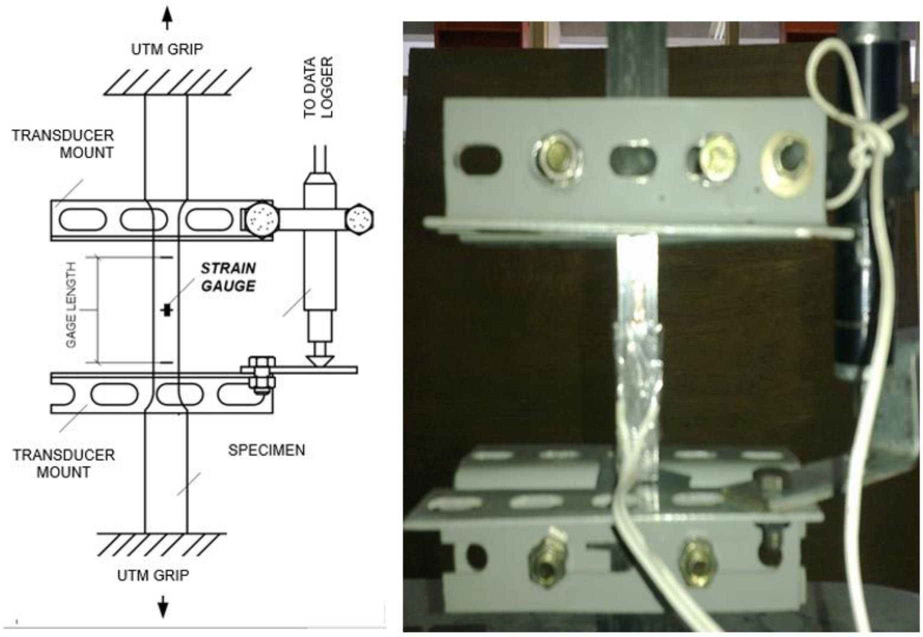


Fig. 4. Size of Zinc plate test specimen according to ASTM a370-03a.

Fig. 5. Zinc plate test object.



(a) **(b)**

Fig. 6. Zinc tensile strength testing: (a) plan and (b) actual.

Before the test, the zinc plate specimen, prepared according to the dimensions shown in Fig. 3, is marked along the gauge length section. Sandpaper is applied to the specimen's enlarged section to improve the testing apparatus's grip. The tensile test uses a Universal Testing Machine (UTM) equipped with a Linear Variable

Differential Transformer (LVDT) and a strain gauge to measure the resulting tensile strain. The UTM applies a uniaxial tensile force to the zinc plate specimen until it undergoes yielding or fracture. A displacement control speed of 6 mm/min is used during the test.

2.2. Mortar compression test

Mortar serves as the primary component in the production of ferrocement. In this study, the mortar utilized has a cement-to-sand ratio of 1:3, designed in accordance with SNI 03-6825-2002, titled *Method of Testing the Compressive Strength of Portland Cement Mortar for Civil Works.* The mortar test specimens were cubic, measuring 5 × 5 × 5 cm, as shown in Fig. 7.

Fig. 7. Creation of mortar test specimens.

2.3. Zinc-coated ferrocement plate flexural test

A total of 24 ferrocement plate test specimens were prepared, each with dimensions of 55 x 20 x 4 cm. The moulds for the test specimens were constructed using plywood and zinc plates. Plywood was utilized for the longer sides of the moulds, while zinc plate sheets were employed for the shorter sides and the base. Only the plywood sections of the moulds were removed after the ferrocement had hardened and reached the desired age. The zinc sections remained attached to the ferrocement due to the nail or nut bonds and were subjected to a flexural test. The ferrocement mould dimensions are shown in Fig. 8. To ensure that the wire mesh did not adhere to the zinc plate, screws were used to secure the mesh (see Fig. 9). Additionally, these screws enhanced the bond between the zinc plate and the ferrocement.

The testing involved 24 zinc-coated ferrocement plate specimens, with variations in the number of wire mesh layers and the curing ages of the specimens (see Table 1). The ferrocement mixture was prepared using a cement-to-sand volume ratio of 1:3, with the sand passing a 0.5 cm sieve. The number of wire mesh layers varied between one and two. Flexural strength testing was conducted on the ferrocement specimens at curing ages of 3, 7, 21, and 28 days.

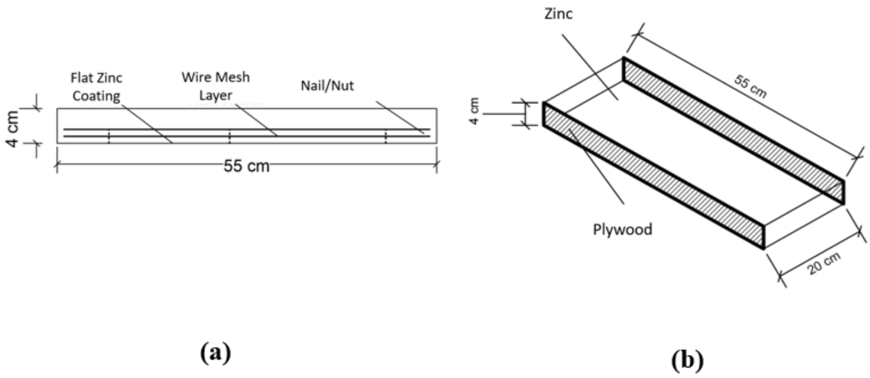


Fig. 8. Dimensions of zinc-coated ferrocement test specimen molds: (a) side view and (b) 3D view.

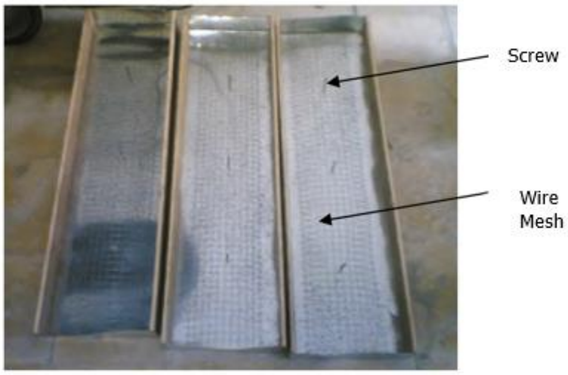


Fig. 9. Installation of wire mesh and screws on ferrocement test molds.

Table 1. Variation in the production and number of ferrocement precast plate test specimens.

Mortar	Amount of Wire Mesh	Specimen Age (days)				Amount of Specimen
		3	7	21	28	
(Cement : Sand = 1:3)	0	2	2	2	2	8
	1	2	2	2	2	8
	2	2	2	2	2	8
Total		**6**	**6**	**6**	**6**	**24**

2.4. Composite material analysis

Zinc-coated ferrocement plates are one-way flexible plates composed of multiple materials, specifically ferrocement combined with zinc. The stress analysis of these one-way flexible plates is based on composite beam flexural theory. The composite material model consists of two materials, labelled material 1 and material 2, as shown in Fig. 10. The flexural equations for the composite material are presented in Eqs. (1) and (2) [15]. These equations provide the normal stress for material 1 (σ_{x1}) and material 2 (σ_{x2}), which are influenced by the applied moment (M), the modulus of elasticity (E_1, E_2), the stress location (y), and the moment of inertia (I_1, I_2) of each material. The determination of the moment of inertia is based on the location of the neutral axis of the composite material, with the values of y_1 and y_2 determined through the integration of Eq. (3).

$$\sigma_{x1} = \frac{M\,y\,E_1}{E_1\,I_1 + E_2\,I_2} \tag{1}$$

$$\sigma_{x2} = \frac{M\,y\,E_2}{E_1\,I_1 + E_2\,I_2} \tag{2}$$

$$\int \sigma_{x1}\,dA + \int \sigma_{x2}\,dA = 0 \tag{3}$$

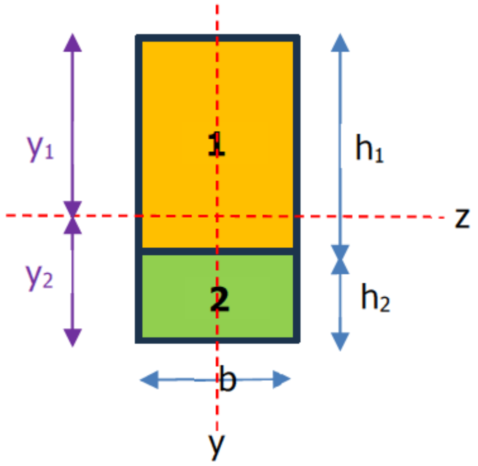


Fig. 10. Composite material.

A composite material remains intact if the normal stress does not exceed its allowable stress. In this study, the stress capacity of the composite material was determined based on the compressive load derived from the flexural strength test results (P), which generates a bending moment (M) as shown in Eq. (4). In this equation, L represents the distance between the supports of the test object, and q denotes the self-weight of the test object.

$$M = \frac{1}{4}PL + \frac{1}{8}qL^2 \tag{4}$$

3. Results and Discussion

The test results for the following ferrocement plate components are presented based on the tests conducted. A flexural stress analysis is also performed, and design drawings for field trials are developed.

3.1. Result and discussion of zinc plate tensile test

The tensile test result of the zinc plate is shown in Fig. 11 as a stress-strain curve. Based on the curve, the yield stress and strain of the zinc plate can be obtained using the 0.2% offset method, the results of which are 194.6 MPa and 0.00496. Therefore, the elastic modulus of zinc is 39233.9 MPa.

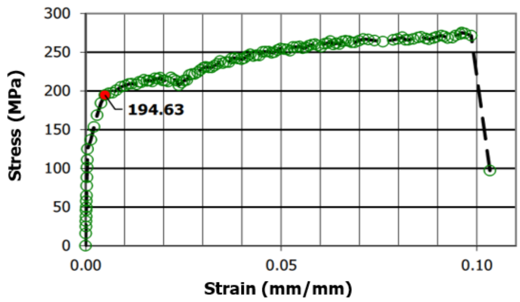


Fig. 11. Stress-strain relationship of zinc plate.

3.2. Results and discussion of mortar compression test

It is essential to conduct a fine aggregate analysis to ensure the accuracy of the mixture proportion in each test object model, which includes testing specific gravity, water absorption, water content, and sieve analysis [16]. The fine aggregate testing revealed that the dry surface specific gravity of the concrete sand used is 2.59, with a water absorption percentage of 2.8%. The volume weight of the concrete sand in its solid condition is 1658.7 kg/m³. Additionally, the sieve analysis results indicate that the concrete sand falls within zone 2, with a fineness modulus value of 3.1. These fine aggregate analysis results meet the requirements specified in SNI 03-6825.

The mortar compression test was conducted at 28 days of age, with three test objects for each cement-to-sand ratio. The average mortar compressive strength was 22.3 MPa. Based on these compressive strength results, the mortar's elastic modulus was 22,194.75 MPa. The tensile strength of the concrete mortar is assumed to be 15% of its compressive strength [17], which gives a tensile strength value of 3.345 MPa.

3.3. Results and discussion of zinc-coated ferrocement plates flexural test

The mould sides (plywood) can be removed after the test specimen (ferrocement mortar mixture) has been left to rest for one day. The base of the mould, consisting of a zinc plate layer, remains attached to the bottom of the test specimen. Subsequently, the specimen's weight is measured to determine the weight of each zinc-coated ferrocement plate [18]. Based on the weight measurements, the average weight of the zinc-coated ferrocement is 10.74 kgf, resulting in an average weight per volume of 2118.2 kgf/m³. These results indicate that the weight per volume of ferrocement is slightly lower than the specific gravity of reinforced concrete, typically greater than 2400 kgf/m³.

Next, the preparation of the testing machine, positioning of the test specimen, and installation of the dial gauge were carried out as shown in Fig. 12. Flexural testing, as shown in Fig. 13, was performed by applying a compressive load to the layered ferrocement plate test specimen. The span used was 45 cm, with the compressive force applied at the midpoint of the span. A dial gauge with an accuracy of 0.01 mm, located beneath the specimen, measured the deflection. During the test, the deflection was recorded for each compressive load increment of 50 kg. Observations continued until the compressive load indicator needle dropped, and visible cracks or failure occurred in the test specimen. The specimen's behaviour was monitored throughout the flexural strength test until failure was observed.

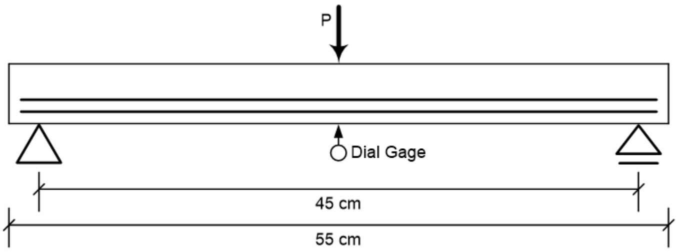


Fig. 12. Flexural test model.

Fig. 13. Flexural testing of ferrocement.

The flexural test results indicated that the 28-day-old zinc-coated ferrocement plate could withstand a flexural compressive load of up to 365 kgf, with a deflection of 0.65 mm. The findings also revealed that flexural strength increases with the number of wire mesh layers and improves as the mortar ages, while deflection decreases. Figures 14, 15, and 16 illustrate the relationship between load and deflection for zinc-coated ferrocement plates using 1:3 mortar, each with varying wire mesh layers. The failure mode observed in all 24 test specimens was consistent: upon reaching the peak load, the ferrocement plate (mortar) on the lower side experienced failure first, while the zinc plate remained elastic (not yet deformed).

3.4. Flexural stress analysis of zinc-coated ferrocement plates

As shown in Fig. 14, the flexural test results indicate a maximum flexural load (P) of 365 kg for the zinc-coated ferrocement plate. Using Eq. (4), the bending moment capacity of the ferrocement plate is calculated to be 0.403 kNm. This bending moment generates normal stress for each composite material, as summarized in Table 2. Additionally, the moment of inertia was calculated using Eq. (3), yielding values of 107.47 cm^4 for the ferrocement plate and 16.01 cm^4 for the zinc plate materials.

Table 2. Stress analysis on zinc-coated ferrocement plate composite material.

No.	Composite Material	Fiber	Normal Stress (MPa)	Information
1	Ferrocement (Mortar)	Top (Compression)	-6.23 MPa	Using Eq. (1)
		Bottom (Tension)	5.64 MPa	Using Eq. (1)
2	Zinc Plate	Bottom (Tension)	11.01 MPa	Using Eq. (2)

The stress analysis results align with the observed behaviour of zinc-coated ferrocement plates during flexural testing. Specifically, the lower fibre stress in the ferrocement, the boundary between the ferrocement and zinc, reaches a tensile stress of 5.64 MPa. This value exceeds the mortar's tensile stress (greater than 3.345 MPa), leading to tensile flexural failure in the fibre section. Meanwhile, the zinc plate material remains elastic, as its stress remains well below the yield stress of the zinc.

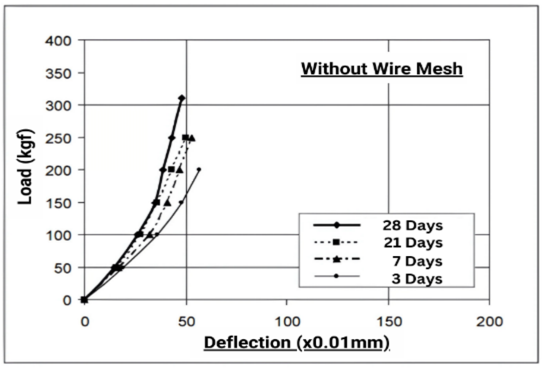


Fig. 14. Relationship between load and deflection on 1:3 ferrocement plate without wire mesh.

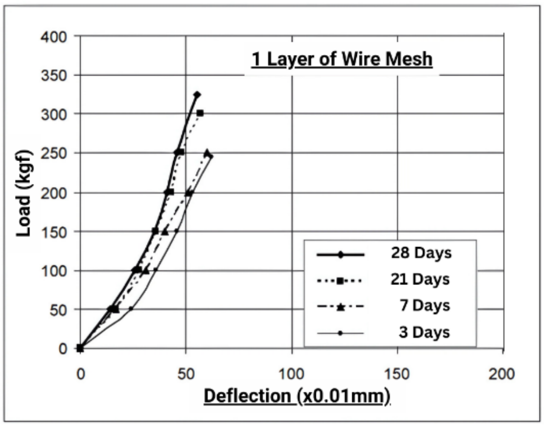


Fig. 15. Relationship between load and deflection on 1:3 ferrocement plate with one layer of wire mesh.

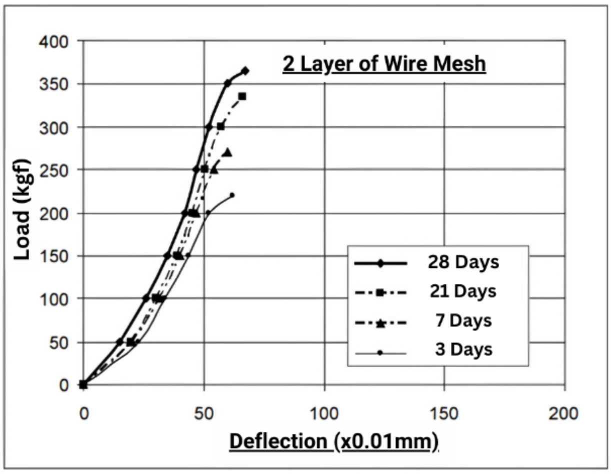


Fig. 16. Relationship between load and deflection on 1:3 ferrocement plate with two layers of wire mesh.

3.5. Test plate design using zinc-coated ferrocement plates

Formwork, a material used in constructing floor slabs, often requires careful selection to help minimize construction costs. Formwork enhances flexural strength when used as a permanent component of floor slabs, reducing the concrete volume and reinforcing steel needed. As floor slabs are typically the largest structural elements in multi-storey buildings, optimizing their design can significantly reduce the overall project cost.

A design was developed for a field trial involving zinc-coated ferrocement plates as an innovative material for permanent formwork in residential floor slabs. The installation details of the zinc-coated ferrocement plates are shown in Figs. 17 and 18. Each plate measures 160 cm in length, corresponding to the distance between two beams, with a thickness of 5 cm and a width of 30 cm. The zinc used has a thickness of 0.2 mm, similar to the tensile strength test specimen. The plates are moulded first and then installed per sheet board as shown in Fig. 19. Upon installation on the beams, the zinc-coated ferrocement plates are reinforced with anchors and attached to the beam reinforcement, as shown in Fig. 20. Once the plates are fully installed, the assembly of the single-layer floor slab reinforcement is completed, followed by casting a 7 cm thick reinforced concrete layer on top.

In line with the method shown in Table 2, the bending moment capacity for the zinc-ferrocement plate should be less than 0.488 kNm to ensure the tensile stress of the ferrocement does not exceed the tensile strength of the mortar. Given that the zinc-ferrocement plate functions as permanent formwork, it is assumed to bear a maximum concentrated load of 80 kg from workers, along with the self-weight of the reinforced concrete plate, which is 50.4 kgf/m. If this assumption holds, the zinc-coated ferrocement plate remains safe, as it produces a bending moment of 0.472 kNm, which is lower than its bending moment capacity, according to Eq. (4). This was confirmed during the field trial, where no structural failures were reported. The floor plate successfully supported live loads.

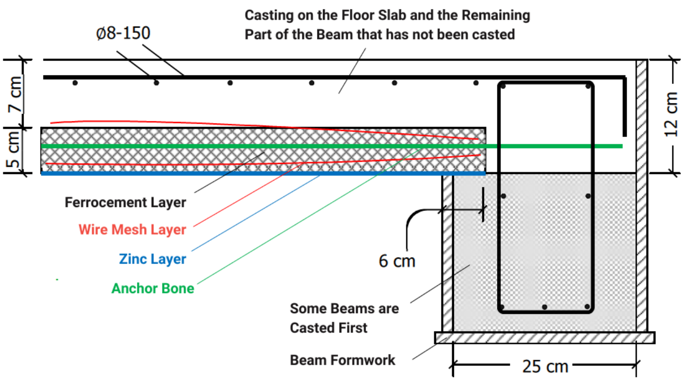


Fig. 17. Zinc-coated ferrocement plate formwork detail A.

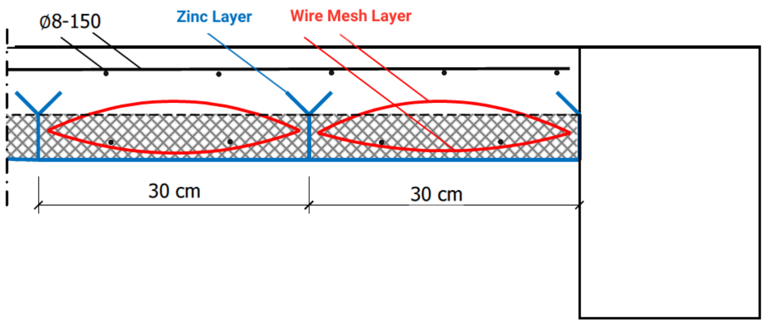


Fig. 18. Zinc-coated ferrocement plate formwork detail B.

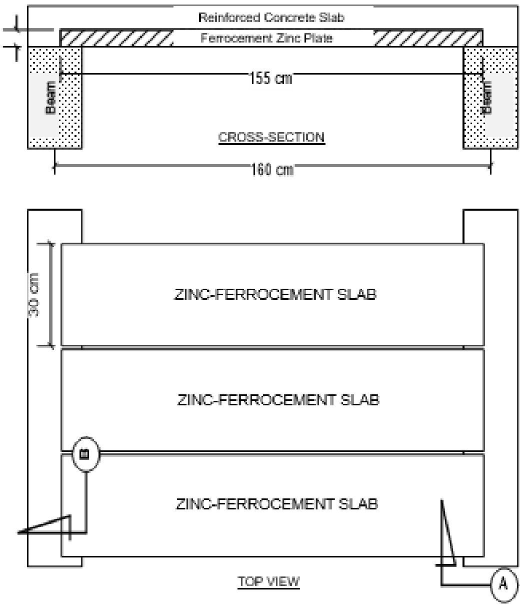


Fig. 19. Zinc-coated ferrocement plate plan.

(a) (b)

Fig. 20. Anchoring of zinc-coated ferrocement plates on beams: (a) before anchoring and (b) after anchoring.

4. Conclusion

Based on the analysis and experimental tests conducted, it can be concluded that ferrocement and zinc plates are suitable for use as formwork for floor slabs in multi-storey buildings. The tensile strength test on 0.2 mm thick zinc produced a yield stress of 194.6 MPa. With a cement-to-sand ratio of 1:3, the mortar achieved a compressive strength of 22.3 MPa. The composite material formed a zinc-coated ferrocement plate demonstrating a flexural strength of 0.403 kNm when combined with two layers of wire mesh and zinc plates. Based on field testing results, zinc-coated ferrocement plates can be safely utilized as permanent formwork for floor slabs in multi-storey buildings.

References

1. Trijieti, T.; Atmawan, F.; and Aswanto, M. (2018). Time and cost comparison of conventional and alternative plate hollow slab, halfslab and metaldeck. *Journal of Science and Technology Research*, 7(1), 61-66.
2. Ibrahim, I.S.; Elliott, K.S.; Abdullah, R.; Kueh, A.B.H.; and Sarbini, N.N. (2016). Experimental study on the shear behaviour of precast concrete hollow core slabs with concrete topping. *Engineering Structures*, 125(1), 80-90.
3. Wariyatno, N.G.; Haryanto, Y.; and Sudibyo, G.H. (2017). Flexural behavior of precast hollow core slab using PVC pipe and Styrofoam with different reinforcement. *Procedia Engineering*, 171(1), 909-916.
4. Singh, M.; and Talwar, M. (2017). Ferrocement as a construction material. *International Journal of Advanced Research in Computer Science*, 8(4), 170-182.
5. Agustin, R.; and Robles-Austriaco, L. (1990). Technological development of low-cost materials in ASEAN countries. *Journal of Ferrocement*, 20(3), 265-279.
6. Subramani, T.; and Siva, R. (2016). Experimental study on flexural and impact behavior of ferrocement slabs. *International Journal of Application or Innovation in Engineering and Management* (*IJAIEM*), 5(5), 228-238.
7. Madadi, A.; Eskandari-Naddaf, H.; Shadnia, R.; and Zhang, L. (2018). Digital image correlation to characterize the flexural behavior of lightweight ferrocement slab panels. *Construction and Building Materials*, 189(1), 967-977.

8. Amala, M.; and Neelamegam, M. (2015). Experimental study of flexure and impact on ferrocement slabs. *IOSR Journal of Mechanical and Civil Engineering*, 1(1), 62-66.
9. Naser, M.Z.; Hawileh, R.A.; and Abdalla, J.A. (2019). Fiber-reinforced polymer composites in strengthening reinforced concrete structures: A critical review. *Engineering Structures*, 198(1), 109542.
10. Obaid, A.H.; and Jaafer, A.A. (2022). Experimental investigation of ferrocement sandwich composite jack arch slab. *Asian Journal of Civil Engineering*, 23(7), 1155-1168.
11. Makhlouf, M.H.; Alaa, M.; Khaleel, G.I.; Elsayed, K.M.; and Mansour, M.H. (2024). Shear behavior of reactive powder concrete ferrocement beams with light weight core material. *International Journal of Concrete Structures and Materials*, 18(1), 46-59.
12. Naser, F.H.; Al-Mamoori, A.H.N.; and Dhahir, M.K. (2021). Effect of using different types of reinforcement on the flexural behavior of ferrocement hollow core slabs embedding PVC pipes. *Ain Shams Engineering Journal*, 12(1), 303-315.
13. Shaheen, Y.B.; Eltaly, B.A.; Yousef, S.G.; and Fayed, S. (2023). Structural performance of ferrocement beams incorporating longitudinal hole filled with lightweight concrete. *International Journal of Concrete Structures and Materials*, 17(1), 21-35.
14. Yuan, S.; Hao, H.; Zong, Z.; and Li, J. (2021). Numerical analysis of axial load effects on RC bridge columns under blast loading. *Advances in Structural Engineering*, 24(7), 1399-1414.
15. Dai, L. (2020). Finite-element model updating of the traditional beam-column joint in Tibetan heritage buildings using uniform design. *Advances in Structural Engineering*, 23(9), 1890-1901.
16. Drougkas, A.; Verstrynge, E.; Hayen, R.; and Van-Balen, K. (2019). The confinement of mortar in masonry under compression: Experimental data and micro-mechanical analysis. *International Journal of Solids and Structures*, 162(1), 105-120.
17. Tan, Y.; Gu, Q.; Ning, J.; Liu, X.; Jia, Z.; and Huang, D. (2019). Uniaxial compression behavior of cement mortar and its damage-constitutive model based on energy theory. *Materials*, 12(8), 1309-1323.
18. Jayaramappa, N.; and Nagendra, C.V.S. (2022). Comparative study on folded ferrocement and plain ferrocement panels subjected to axial loading. *Materials Today*: *Proceedings*, 57(1), 2134-2139.