**FLEXURAL PERFORMANCE OF FERROCEMENT BASED ON SUSTAINABLE HIGH-PERFORMANCE MORTAR A REVIEW**

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**Abstract**

To achieve economical and sustainable construction, it is essential to comprehend the behavior of the chosen building material. The evaluation of the flexural performance of ferrocement, utilizing sustainable high-performance mortar, focuses on assessing the material's capacity to endure bending or flexural stress. Ferrocement is a composite material comprising cement mortar reinforced with a mesh or metal framework. The effectiveness of ferrocement can be heightened by incorporating sustainable high-performance mortar, commonly composed of environmentally friendly and durable materials. Mortar containing metakaolin (MK), revealing that MK as a partial cement replacement improves compressive strength while reducing workability and porosity. Fiber reinforcement enhances flexural toughness, preventing crack initiation and significantly improving the post-crack zone. Ferrocement, employed in low-cost constructions, proves to be a cost-effective construction material. It involves the combination of cement mortar with closely spaced wire mesh, commonly referred to as chicken wire mesh. The ferrocement process simplifies construction by eliminating coarse aggregates, distinguishing it from reinforced concrete. This paper focuses on examining how various characteristics of warp knitted fabric impact the flexural properties of ferrocement composites. Ferrocement composites find diverse applications in the construction industries. The review paper summarizes the finding based upon the research paper.

**Keywords:** Cost analysis, Ferrocement, Metakaolin Silica fume Sisal fibers.

**Introduction**

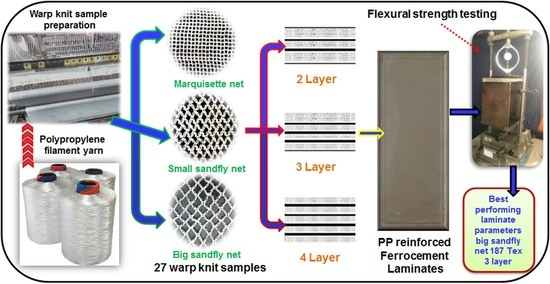
The plain cementitious matrix, encompassing non-reinforced mortar or concrete, is characterized by brittleness and limited deformation capacity, coupled with low tensile strength [1]. In comparison to reinforced concrete or mortar, non-reinforced cement-based composites exhibit low ductility, resistance to crack propagation, and tensile strength. Inherent microstructural features and volumetric changes during manufacturing result in the manifestation of micro-cracks or flaws even before the application of any load [2]. In reinforced concrete or mortar, the failure mode tends to be ductile owing to the nature of the reinforcement, yet it is susceptible to extensive cracking. The widening of cracks and deflection contribute to the deterioration of non-structural components and compromise structural integrity due to steel bar corrosion. Consequently, the maintenance of such structures necessitates effective repair materials and skilled labor, incurring additional costs beyond the initial construction expenses. To address these challenges and enhance the service life of structures, there is a need to explore high-performance building materials capable of partially substituting for reinforced concrete. The flexural performance of ferrocement based on sustainable high-performance mortar involves the study of the material's ability to withstand bending or flexural stress. Ferrocement is a composite material that consists of cement mortar reinforced with a mesh or metal framework. The performance of ferrocement can be enhanced by using sustainable high-performance mortar, which typically includes environmentally friendly and durable materials. Understanding the behavior of building materials is crucial when selecting materials for economical and sustainable construction. This research focused on investigating the properties of eco-friendly high-performance mortar (HPM) used in the production of ferrocement. The experimental program was structured into four phases. In the initial phase, non-reinforced HPM with 20% Supplementary Cementitious Materials (SCM) was examined. The second phase delved into the behavior of HPM reinforced with natural sisal fibers (NSF) ranging from 0.5% to 1.5%. The third phase evaluated the performance of ferrocement made from both non-reinforced and reinforced HPM under bending stresses. The final phase assessed the economic feasibility of the research. Results indicated that incorporating 9% silica fume and 11% metakaolin by weight of cement enhanced HPM properties compared to other percentages. The addition of NSF improved flexural strength, flexural toughness, splitting tensile strength, and elastic modulus while affecting flowability, compressive strength, and UPV. Additionally, the flexural behavior of ferrocement units improved with NSF incorporation. A cost analysis comparing conventional reinforced concrete and ferrocement panels for roofing demonstrated a 27% reduction in initial cost and an 83% decrease in dead load. Over the past three decades, ferrocement has undergone significant development and has evolved into an advanced building material in terms of design and fabrication [3]. The utilization of the Ferrocement approach has demonstrated positive effects on cost reduction and environmental impact, proving particularly beneficial for constructing emergency shelters and low-cost housing in disaster-affected cities [4]. This material is composed of hydraulic cement mortar reinforced with closely spaced layers of relatively small wire diameter mesh [5]. Numerous researchers have explored the potential of ferrocement as a promising building material [6]. Researcher conducted a study on the performance of ferrocement in roofing systems, revealing that cement mortar reinforced with steel fibers can be employed to produce ferrocement roof panels. The study also highlighted that increasing the number of steel wire mesh layers enhances the flexural strength of ferrocement units. In a comparison by Mughal et al. [7] between ferrocement units reinforced with polypropylene (FP) and galvanized iron meshes (FG), it was observed that FG exhibited superior mechanical behavior in compression and bending tests, whereas FP demonstrated better ductility properties. Memon et al. [8] delved into the behavior of high-workability mortar for ferrocement production. Various amounts of Supplementary Cementitious Material (SCM), specifically slag, and superplasticizer were utilized to design high workability. The study indicated that the addition of superplasticizer enhances the workability of mortar, and thin ferrocement elements can be cast using high-strength SCM-cement mortar. Scholar [9] documented the impact of silica fume (SF) and steel fibers on ferrocement properties. Incorporating SF (15% by weight of cement) and reinforcing the cementitious matrix with 4% steel fibers positively influenced crack resistance and flexural strength. Researcher [10] explored SF's effect on the mechanical behavior of high-performance concrete, revealing increased compressive strength, splitting tensile strength, and elastic modulus in the presence of SF. Despite the overall enhancement of cement-based composites with SF [11], a high SF dosage may lead to hydration heat, posing potential hazards related to shrinkage problems [15]. Consequently, researchers have explored substitute materials, such as metakaolin, with positive environmental impacts and benefits to the cementitious matrix properties [12]. Scholar [13] assessed the mechanical properties of mortar containing metakaolin (MK), concluding that MK as a partial replacement of cement improves compressive strength while reducing workability and porosity. Researcher [14] demonstrated the effectiveness of using MK along with other Supplementary Cementitious Materials (SCM), like fly ash, as a partial cement replacement in high-performance concrete. This mixture enhanced compressive strength, flexural strength, tensile strength, and durability. Researcher [15] investigated the use of natural fibers in cement mortar and concrete. Scholar [16] studied concrete reinforced with sisal fibers (NSF), revealing increased tensile strength and elastic modulus but decreased workability and compressive strength with NSF incorporation. Researcher [17] compared concrete reinforced separately with polypropylene and sisal fibers, noting that sisal fibers provided comparable flexural strength to synthetic fibers like polypropylene, imparting ductility and flexural toughness to concrete. The use of natural, renewable, and cost-effective fibers instead of commercial counterparts offers benefits such as reduced carbon dioxide (CO2) emissions from industrial processes, conservation of raw materials, and cost savings [18].

Hence, the primary goals of this review article are to find out the research gap and formulate an eco-friendly high-performance building material reinforced with natural fibers, manufacture ferrocement units utilizing the developed building material, and assess their flexural performance. Additionally, the article also aims to summarize a cost comparison between conventional construction methods and Ferrocement technology.

**Literature Review**

To achieve economic and sustainable construction, the choice of building material necessitates a comprehensive understanding of its behavior. Consequently, this study delves into the behavior of environmentally friendly high-performance mortar (HPM) employed in the production of ferrocement. The research is structured into four phases, starting with the investigation of optimal non-reinforced HPM, containing 20% Supplementary Cementitious Materials (SCM), in the initial phase. The second phase explores the behavior of HPM reinforced with varying percentages (0.5%–1.5%) of natural sisal fibers (NSF). Subsequently, the third phase assesses the performance of ferrocement, produced from both optimal non-reinforced and reinforced HPM, under bending stresses. Finally, the fourth phase introduces an analysis of the economic feasibility of the research.

Results indicate that incorporating silica fume and metakaolin at 9% and 11% by weight of cement, respectively, enhances HPM properties compared to other percentages. The addition of NSF improves flexural strength, flexural toughness, splitting tensile strength, and elastic modulus, while affecting flowability, compressive strength, and UPV negatively. Furthermore, the flexural behavior of ferrocement units sees improvement with the inclusion of NSF. A cost analysis comparing conventional reinforced concrete with ferrocement panels as a roofing system reveals a reduction in the initial cost and dead load of the roof by approximately 27% and 83%, respectively. Jeveea et al., 2017 imperative to meet the demand for low-cost housing necessitates the development of affordable building elements utilizing locally available materials. In rural areas, where bamboo is abundant, it can serve as a cost-effective alternative to conventional M.S. or HYSD bars, which are relatively expensive. Additionally, fly ash, a by-product from thermal power plants, presents an opportunity to replace cement in standard mortar or concrete formulations. To enhance the serviceability limit, this study explores the flexural behavior of ferrocement slab panels constructed with bamboo and reinforced with layers of chicken wire mesh. The experimental investigations focus on simply supported ferrocement slab panels subjected to a monotonically increasing uniformly distributed load. The experimental program includes testing 12 ferrocement slab panels, each with dimensions of 470 mm × 940 mm and thicknesses of 40 mm and 50 mm, comprising 6 slabs each. Among these slabs, 6 were constructed with conventional mortar (1:3 ratio), and the remaining 6 featured a 15% cement replacement with fly ash. The latter slabs incorporated bamboo strip grids as skeletal reinforcement. The slabs were cast, cured under wet gunny bags for 28 days, and subsequently tested under uniformly distributed loading. The obtained test results were then compared with theoretical expectations. The results reveal that the first crack load and the experimental failure load are nearly identical for both types of slabs. The ultimate load is approximately double the first crack loads. Notably, all slabs displayed considerable ductility before experiencing final failure in flexure.



Flexural Behaviour of Ferrocement (Manickam Rameshkumar et al., 2022). [19].

Amala.et al., 2013 expressed that in recent years, there has been a notable rise in public concern regarding the management of medical waste. This study compares the permeability and compaction characteristics of soil-fly ash mixtures incorporating varying percentages of medical fly ash to assess the viability of recycling medical waste ash. The fly ash is blended with a residual deposit of locally known Gatch, an in-situ weathered and degraded weakly cemented calcareous/gypsiferous silty sandstone material, for potential utilization in geo-environmental applications. Fly ash, a byproduct of incineration, represents the primary method employed to manage the substantial volumes of medical waste generated in the country. This approach aims to reduce the disposal volumes of fly ash and mitigate potential environmental risks. A comprehensive laboratory testing program was conducted to characterize the properties of white Gatch. Subsequently, fly ash was introduced in various proportions (0%, 0.1%, 1%, 2.5%, and 5% by dry weight of soil) to Gatch samples. The resulting fly ash-Gatch mixtures were scrutinized to assess their engineering performance. A general improvement in soil properties attributed to the distinctive characteristics of fly ash was observed, suggesting its potential application in geo-environmental contexts, such as landfill liners. Generally, an increase in the percentage of medical fly ash led to a decrease in the permeability of fly ash-Gatch mixtures, reaching a point of minimal change beyond a content of 1%. The properties of plaster can be influenced by various factors such as the materials employed, mix composition, mechanical bond between the plaster and supporting surface, and overall work quality. There is a rising demand for ferro-cement as a construction material, which is crafted from diverse silicon and aluminum-rich components like fly ash, rice husk ash, silica fume, metakaolin, and blast furnace slag. Utilizing ferro-cement mortar contributes to reduced pollution, as it results in lower CO2 emissions into the atmosphere. Author focuses on investigating the behavior of eco-friendly high-performance mortar (HPM), specifically employed in ferrocement production. The examination will assess the performance of mortars containing different proportions (0%-15%) of silica fume (SF) and metakaolin (MK), along with natural sisal fibers (NSF). Additionally, test-casting will be conducted using a cube measuring 50 x 50 x 50 mm to evaluate compressive strength and durability. The adverse impact of silica fume (SF) on workability is mitigated, and mechanical performance is enhanced when metakaolin (MK) and SF are utilized with cement in mortar as partial replacements. The optimal performance is observed at 28 days when a mixture of 5–10% SF and 10% MK is incorporated. Due to its thinner section, increased strength, and easy installation, ferrocement found application in unreinforced masonry walls. The experimental setup included walls with and without window openings. Various retrofitting configurations with ferrocement were employed, subjecting the walls to cyclic loading and shaking. Different orientations of ferrocement belts—horizontal, vertical, both horizontally and vertically, and diagonally—were implemented to mimic actual earthquake behavior for analysis. In walls without openings, cracks first emerged at the foundation level. When openings were introduced, cracks initiated at the opening interface and then extended into the mortar layer. The use of horizontal belts effectively halted crack propagation at the top portion, with no significant appearance of diagonal cracks. However, vertical belts resulted in the generation of diagonal cracks. The retrofitting with ferrocement demonstrated an enhancement in the ductility of the walls. Ductility behavior improved two to threefold with ferrocement retrofitting.

The inherent characteristics of a plain cementitious matrix, such as non-reinforced mortar or concrete, render it brittle and non-deformable with low tensile strength. In comparison to reinforced concrete or mortar, non-reinforced cement-based composites exhibit significantly lower ductility, resistance to crack propagation, and tensile strength. Micro-cracks or flaws are evident in these matrices even before any external load is applied, owing to their inherent microstructure and volumetric changes during manufacturing. While reinforced concrete or mortar demonstrates a ductile failure type due to the nature of reinforcement, it is prone to extensive cracking. The widening of cracks and deflection can lead to damage in non-structural members and compromise structural elements due to steel bar corrosion. Consequently, structures of this kind require effective repair materials and skilled labor for maintenance, incurring additional costs beyond the initial construction expenses. To address these challenges and extend the service life of structures, there is a need to explore high-performance building materials that can partially replace traditional reinforced concrete. Ferrocement, developed predominantly in the past three decades, has evolved into an advanced building material in terms of design and fabrication. The Ferrocement construction approach offers benefits such as cost reduction, reduced environmental impact, and suitability for emergency shelters and low-cost housing in disaster-affected cities. It comprises hydraulic cement mortar reinforced with closely spaced layers of relatively small wire diameter mesh. Numerous researchers have explored the potential use of ferrocement as a promising building material.

The performance of ferrocement in roofing systems was investigated, demonstrating that cement mortar reinforced with steel fibers can produce ferrocement roof panels. Additionally, increasing the number of steel wire mesh layers improves the flexural strength of ferrocement units. Compared ferrocement units reinforced with polypropylene (FP) and galvanized iron meshes (FG), noting that FG exhibits superior mechanical behavior in compression and bending tests, while FP demonstrates better ductility properties. A study delved into the behavior of high workability mortar for ferrocement production. Various amounts of SCM (slag) and superplasticizer were utilized to enhance workability, revealing that the inclusion of superplasticizer improves mortar workability. Furthermore, thin ferrocement elements can be cast using high-strength SCM-cement mortar. the impact of silica fume (SF) and steel fibers on ferrocement properties. Incorporating SF (15% by weight of cement) and reinforcing the cementitious matrix with 4% steel fibers positively influenced crack resistance and flexural strength. SF's influence on high-performance concrete, noting increases in compressive strength, splitting tensile strength, and elastic modulus. While SF enhances overall properties of cement-based composites, excessive usage may lead to heat of hydration issues and shrinkage problems Thus, researchers have explored alternative materials like metakaolin, known for its positive environmental impact and effects on cementitious matrix properties.

Mortar containing metakaolin (MK), revealing that MK as a partial cement replacement improves compressive strength while reducing workability and porosity. MK's use with other supplementary cementitious materials (fly ash) in high-performance concrete, enhancing compressive strength, flexural strength, tensile strength, and durability. Numerous studies have investigated the potential of natural fibers in cement mortar and concrete. Concrete reinforced with sisal fibers (NSF), finding that NSF incorporation enhanced tensile strength and elastic modulus but reduced workability and compressive strength. Compared concrete reinforced separately with polypropylene and sisal fibers, discovering that sisal fibers provided comparable flexural strength to synthetic fibers like polypropylene, contributing ductility and flexural toughness to concrete. The use of natural, renewable, and cost-effective fibers instead of expensive commercial fibers has garnered attention.

**Conclusion:**

The combination of metakaolin (MK) and silica fume (SF) in mortar, as a partial substitute for cement, mitigates the adverse impact of SF on workability and enhances mechanical performance compared to using SF or MK alone. Optimal performance at 28 days is achieved with a 9% SF and 11% MK mixture. The introduction of natural sisal fiber in High-Performance Mortar (HPM) leads to a slight reduction in compressive strength and UPV. This reduction, irrespective of curing age, becomes more pronounced with increasing volume fraction. Strengthening HPM with 1% sisal fibers results in a notable improvement in flexural strength, splitting tensile strength, and elastic modulus, showing increases of approximately 22%, 66%, and 22%, respectively, compared to non-reinforced mortar at 90 days. Fiber reinforcement enhances flexural toughness, preventing crack initiation and significantly improving the post-crack zone. Ferrocement units incorporating 1% sisal fiber and PVC-coated steel wire mesh demonstrate robust reinforcement compared to plain ferrocement units. Adding extra reinforcing layers linearly increases the flexural strength by (6–8) % for each additional layer in plain ferrocement. However, the use of more than two reinforcing layers in fibrous ferrocement shows diminishing returns compared to plain ferrocement.

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