Analysis Of Ferrocement & Its Composites Under Sodium Sulphate

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***Abstract*—Ferrocement is a form of reinforced mortar consisting of closely spaced wire mesh embedded in a cement–sand matrix. It offers advantages such as high strength-to-weight ratio, crack resistance, and the ability to be molded in various shapes. These properties make it suitable for applications in water tanks, marine structures, housing, and repair works. Despite these advantages, ferrocement structures are vulnerable to chemical attack, particularly in environments containing sulphates. Sulphate ions react with cement hydration products, leading to expansion, cracking, and loss of strength. This limits its use in coastal, industrial, and wastewater environments. To address these issues, modifications such as the incorporation of fly ash and fibers have been proposed. Fly ash reduces permeability and improves resistance to chemical ingress, while carbon fibers enhance tensile strength and crack resistance. This study aims to evaluate the effect of sodium sulphate curing on ferrocement and assess the performance of modified mixes in comparison with conventional specimens. This was done by casting 36 cubes of varied ferrocement matrices; 18 cured in water of which 9 were cured for 14 days and 9 for 28 days. These 9 cubes consisted of 3 control ferrocement cubes, 3 cubes with 25% fly ash replacement of cement & 3 cubes reinforced with carbon fiber. Similarly, 18 such cubes were cured in 1% Na_2SO_4 solution for 14 and 28 days of similar composites.**

***Index Terms*—ferrocement, carbon fiber, fly ash, sodium sulphate, chicken mesh, woven mesh, compressive strength.**

I. INTRODUCTION

Ferrocement is a composite form of reinforced mortar comprising a closely spaced wire mesh embedded within a cement–sand matrix. It exhibits favourable characteristics such as a high strength-to-weight ratio, enhanced crack resistance, and the capability to be cast into complex geometries. These attributes render ferrocement suitable for a wide range of civil engineering applications, including water storage tanks, marine and offshore structures, low-cost and prefabricated housing, as well as structural rehabilitation and repair works [1]. However, despite these advantages, ferrocement systems are susceptible to degradation under chemical attack, particularly in sulphate-rich environments. Sulphate ions interact with the hydration products of Portland cement, forming expansive phases such as ettringite and gypsum that induce volumetric expansion, microcracking, and subsequent loss of mechanical strength and durability [1], [3]. Consequently, the application of ferrocement in coastal regions, industrial zones, and wastewater treatment facilities is significantly constrained.

To mitigate these durability concerns, various mix modifications have been proposed, notably the incorporation of supplementary cementitious materials and fiber reinforcement. The inclusion of fly ash as a partial cement replacement reduces matrix permeability, refines pore structure, and thereby enhances resistance to sulphate ingress and other aggressive agents [3]. Concurrently, the addition of advanced modifiers such as nano silica and fibres has been shown to improve matrix densification, crack resistance, and long-term durability of ferrocement composites [2].

The present study is designed to investigate the influence of sodium sulphate curing on the mechanical and durability performance of ferrocement composites and to compare the behaviour of modified mixes incorporating fly ash and carbon fibers with that of conventional ferrocement specimens.

II. LITERATURE REVIEW

Nivate et al. discussed the use of conventional wire mesh, with no addition of fibrous material such as carbon fiber, i.e., the effect of advanced fibers on durability is not explored [1]. This lack of examination into the benefits of incorporating advanced materials limits the understanding of how modern innovations could enhance the performance of ferrocement structures. The study used $MgSO_4$ as the chemical medium for their experiments; however, there was no examination of the potential benefits or implications of using Na_2SO_4 as an alternative, which may yield different results in terms of chemical reactions and overall material integrity. Furthermore, the comparison was solely made with conventional ferrocement, which overlooks the growing body of research that highlights the advantages of using cementitious replacements, such as fly ash. By not including these replacements, the study fails to address the sustainability aspects and cost-effectiveness that could be achieved through their integration. The omission of alternative materials and methods suggests a need for further research that encompasses various formulations, as this could lead to more resilient, durable, and environmentally friendly construction practices within the field of ferrocement technology. Exploring these avenues can enhance our understanding of how different materials interact and improve structural performance.

Dhasarathan et al., in their study, did not use conventional ferrocement, rather a geopolymer based ferrocement [2]. This raises questions regarding the comparability of the results to traditional ferrocement structures, as the mechanical properties and durability might differ significantly from the existing body of research. Moreover, the researchers did not include control specimens in their experimentation, which are typically essential for establishing a baseline for performance metrics. Without control samples for reference, it becomes challenging to gauge the effectiveness and reliability of the new approaches they investigated. Additionally, the absence of exposure to sulphate environments is another critical factor since such conditions can dramatically impact the longevity and structural integrity of concrete materials, as Na_2SO_4 is one of the most abundant salts in seawater. The effects of sulphate attack are well-documented, making their exclusion a notable limitation in the study's scope.

Bhikshma et al. discussed the durability of polymer and fly ash modified ferrocement and their corrosion resistance through an impressed voltage test [3]. This method involves applying a specific electrical current to the material, allowing researchers to evaluate the resistance of ferrocement structures under corrosive environments. Their findings indicated that the incorporation of polymers significantly enhances the mechanical properties of ferrocement, leading to improved flexibility and tensile strength. Additionally, the use of fly ash, a byproduct of coal combustion, not only contributes to the sustainability of the construction material but also promotes better workability and reduces permeability.

The study further highlighted the synergistic effects of using both polymer and fly ash, showing that the combined modifications resulted in a more robust material that can withstand harsh conditions, such as exposure to chlorides and sulfates, which are common in coastal and industrial environments. Moreover, the results of the impressed voltage test provide a quantifiable measure of the corrosion resistance, critical for predicting the lifespan and maintenance needs of ferrocement structures. This comprehensive investigation into the properties and performance of modified ferrocement paves the way for advancing construction techniques, particularly in regions where durability against environmental stressors is paramount. The research not only supports the ongoing efforts to enhance construction materials but also contributes to the broader field of sustainable engineering practices, highlighting the potential for reducing the ecological footprint of building materials [3].

III. METHODOLOGY

1. Material details:

1.1 Ordinary Portland Cement (OPC) Grade 53

We used OPC 53 for the ferrocement mortar, as it is readily available in the market and is relatively inexpensive compared to other alternatives. Its cost-effectiveness allows for substantial savings, especially in large-scale constructions, while still providing the necessary structural integrity. It was stored in dry conditions to avoid moisture contamination and was checked visually for any lumps. It ensures that the mortar can achieve a significantly cohesive bond, thereby enhancing the overall resilience of the ferrocement structures. Additionally, its fast-setting nature accelerates the construction process, which can prove beneficial in time-sensitive projects. Utilizing OPC 53 also simplifies the procurement process, as it is commonly stocked by most suppliers, ensuring that builders can maintain continuity in their projects without unnecessary delays.

Figure 1: A bag of OPC Grade 53.

1.2 Crushed Sand:

Crushed sand was used for the matrix of ferrocement. This particular choice of material not only contributed to the structural integrity of the construction but also ensured a consistent quality throughout the composition. The angularity of the crushed sand particles was instrumental in facilitating a stronger bond, providing a robust surface for the cement to adhere to effectively. Additionally, the use of locally sourced crushed sand minimized transportation costs and reduced the project's overall carbon footprint, further enhancing its sustainability aspect. The fine texture of the sand contributed to a smoother finish, allowing for fine detailing in the final product and improving the aesthetic appeal of the ferrocement structures. It was ensured that the sand was free from any organic matter, clay and silt.

Figure 2: A heap of crushed sand.

1.3 Wire Mesh:

A combination of hexagonal wound chicken mesh and woven square mesh was used in the reinforcement for the provision of tensile strength. Chicken mesh is a versatile material composed of interwoven wires that form a hexagonal pattern. It is a cheap wire mesh primarily used for fencing chicken coops; hence the name chicken mesh. Woven mesh is a simple grid of thin steel wires interwoven to form a mesh. Both the meshes were cut into 14 cm in length & 14 cm in width squares in order to maintain uniform cover within the mold.

Figure 3: Woven mesh.

Figure 4: Chicken mesh.

1.4 Fly ash:

Fly ash was used as a partial replacement of cement at

25% by weight, which has been shown to improve various properties of concrete. It was dry mixed with cement for uniform mixing before adding water to ensure optimal distribution of the fly ash throughout the mixture. This method not only facilitates even curing but also enhances the workability and durability of the resulting concrete. The incorporation of fly ash can lead to reduced permeability, which has significant implications for improving the longevity of structures. Furthermore, using fly ash contributes to sustainability by recycling industrial by-products, reducing the overall carbon footprint associated with cement production.

Figure 5: Fly ash.

1.5 Carbon Fiber Strands:

A sheet of carbon fiber was cut into strands for the ease of including it into the ferrocement matrix. These strands, known for their lightweight and robust characteristics, were placed manually during the casting process to avoid clustering. Carbon fiber significantly improves tensile strength, crack resistance, and overall structural integrity. In addition, its resistance to environmental degradation further enhances the durability of the ferrocement, making it particularly suitable for use in various applications, including infrastructure and architectural elements. Thus, the integration of carbon fiber transforms conventional ferrocement into a superior material.

Figure 6: Carbon fiber strands.

2. Mix Design

A cement to sand ratio of 1:3 by weight was adopted for mortar preparation. The water cement ratio was maintained at 0.4 to achieve adequate workability and strength, ensuring the mixture can be easily manipulated during application. Dry materials were mixed thoroughly to ensure uniform distribution of cement, sand, and fly ash, which enhances the overall performance of the mortar. The prepared mix was used immediately for casting to maintain consistency and workability, preventing any potential issues related to premature setting or dry-out, which could compromise the structural integrity of the final product.

3. Casting details:

3.1 Control specimens:

Mortar
Woven mesh
Chicken mesh
Mortar
Woven mesh
Chicken mesh
Mortar

Here, mortar means cement & crushed sand mix.

3.2 Fly ash specimens:

Mortar
Woven mesh
Chicken mesh
Mortar
Woven mesh
Chicken mesh
Mortar

Here, mortar means cement, crushed sand and 25% of cement replaced as fly ash.

3.3 Carbon fiber specimens:

Mortar
Woven mesh
Chicken mesh
Mortar
Carbon fiber strands
Mortar
Woven mesh
Chicken mesh
Mortar

Here, mortar means cement and crushed sand mix.

3.4 Casting procedure:

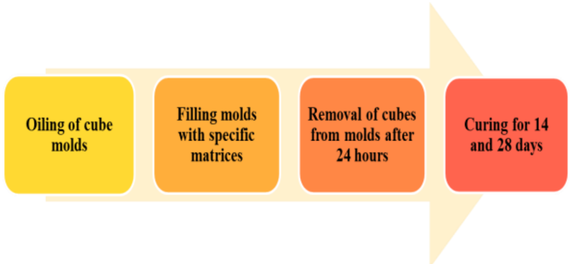

Figure 7: A flow chart of casting procedure.

4. Curing

After casting, the specimens were left undisturbed in the moulds for 24 hours to allow initial setting. The cubes were then carefully demoulded and labeled according to their designated curing group. Control specimens were immersed in clean water for normal curing, while chemical exposure specimens were immersed in a 1 percent sodium sulphate solution for sulphate curing. All specimens were kept fully submerged throughout the curing period, with solution levels maintained above the specimen surface to ensure uniform exposure. Curing durations of 14 and 28 days were adopted for both groups. Upon completion of curing, the specimens were removed, surface dried, and prepared for compressive strength testing.

5. Testing of cubes:

Cubes were tested on a Universal Testing Machine (UTM) to check their compressive strength. The UTM has a capacity of 600 kN, which allows for thorough examination of the material properties under significant loads. After the failure of each cube, the machine provided a graph of time versus displacement to indicate the time taken for the displacement of the machine's upper head, which is crucial for understanding the behavior of the material during the loading process. It gave a one-page report of the cube with important details such as the maximum load taken for failure and the strength of the cube in MPa, providing essential insights into the performance characteristics of the material. Furthermore, the data collected from these tests play a vital role in quality assurance and helps in making informed decisions about the usability of the material in various engineering applications. This process ensures that only the materials meeting the required standards are utilized in construction, thereby enhancing safety and reliability.

Figure 8: Universal Testing Machine.

IV. RESULTS

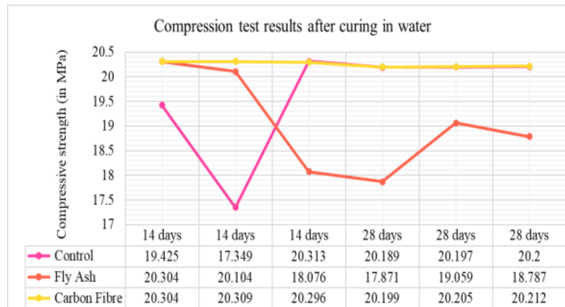

Figure 9: A chart depicting the compression test results of specimens cured in water.

Specimens cured in water showed compressive strength values ranging approximately between 17 MPa to 20.3 MPa. Most specimens achieved strengths close to 20 MPa, indicating proper hydration and robust strength development throughout the curing process. This ability to reach such strength demonstrates the effectiveness of the materials used and the techniques employed in fabrication. Results show good consistency with minimal variation, reflecting uniform mixing and proper compaction during casting. This uniformity is crucial as it suggests a reliable quality control process, ensuring that all batches of ferrocement maintain similar properties. A few lower strength values around 17 to 18 MPa may be due to minor air voids or slight inconsistencies in casting. These discrepancies, while minimal, underscore the importance of monitoring the mixing and pouring process closely to mitigate any factors that could affect structural integrity. Load versus displacement behaviour showed a gradual increase in load followed by controlled failure, which is essential for applications requiring predictable performance under stress. The specimens did not exhibit sudden brittle failure, indicating ductile behavior of ferrocement, which is preferable for construction as it allows for warning signs before collapse. Good bonding between mortar and reinforcement is observed from consistent strength values throughout the specimens. Overall performance confirms that ferrocement develops adequate strength under normal water curing practices, making it a viable option for diverse structural applications. The results suggest that further research into optimizing the mix ratios and curing methods could lead to even higher performance characteristics.

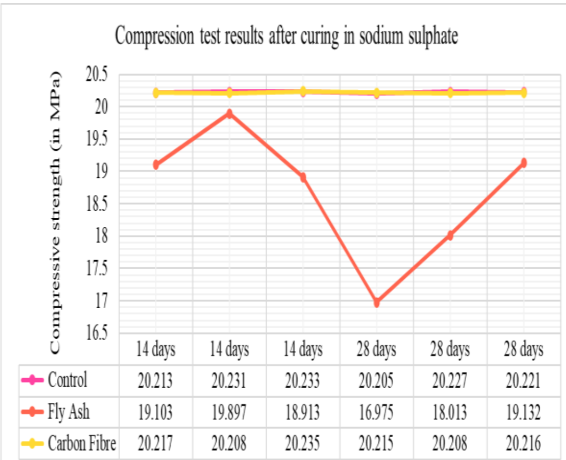

Figure 10: A chart depicting the compression test results of specimens cured in sodium sulphate.

As for specimens cured in sodium sulphate, compressive strength values ranged approximately between 16.9 MPa to 20.3 MPa. Most specimens still achieved strengths close to 20 MPa, showing that ferrocement retains strength under chemical exposure to a significant degree. A few samples showed reduced strength around 17 to 18 MPa, indicating the effect of sulphate attack, which can disrupt the chemical bonds that contribute to material integrity. Overall variation in strength is slightly higher compared to water cured specimens, suggesting that different curing methods yield different resilience levels to chemical influences. Sodium sulphate exposure caused minor deterioration in strength due to chemical interaction with the cement matrix, highlighting the potential risks associated with environmental conditions that introduce aggressive agents. Load versus displacement behaviour showed gradual loading and controlled failure, similar to water cured specimens, reinforcing the material's capacity to absorb energy efficiently under stress. No sudden brittle failure was observed, indicating that structural integrity is still maintained despite adverse conditions. The bond between mortar and reinforcement remained effective throughout the test, revealing the material's durability. Results indicate that sulphate attack has a gradual and limited effect within the tested duration. This underscores the importance of ongoing evaluations and possibly implementing preventive measures to enhance the longevity and performance of ferrocement structures in sulphate-rich environments.

V. CONCLUSION

Water curing provides ideal conditions for hydration and strength gain in ferrocement, which is critical to achieving its full potential. The presence of moisture ensures that the cement particles fully hydrate, resulting in a dense microstructure that enhances durability. Ferrocement exhibits consistent and reliable compressive strength under normal curing conditions, reflecting its ability to withstand various loads. The material shows good structural integrity and controlled failure behavior, which is particularly important for safety in structural applications. The results establish a strong baseline for comparison with chemically cured specimens, highlighting the advantages of traditional methods. Proper casting, compaction, and curing significantly influence the strength performance of ferrocement, emphasizing the need for skilled craftsmanship and adherence to best practices in construction. Ensuring uniformity in thickness and minimizing voids during casting can further optimize the material's performance, providing greater resilience against environmental factors. A comprehensive understanding of these aspects can lead to improvements in design and application techniques, ultimately contributing to the advancement of ferrocement technology.

Ferrocement retains adequate compressive strength even under sodium sulphate exposure, making it a reliable material for construction purposes. Strength reduction due to sulphate attack is moderate and not severe within 14 and 28 days, highlighting its durability in the short term. The material shows resistance to early-stage chemical deterioration, which is crucial for maintaining the integrity of structures, especially those exposed to various environmental factors. Structural behaviour remains stable with controlled failure characteristics, allowing for predictable performance under stress. Ferrocement can be considered suitable for use in mildly aggressive environments, such as coastal zones or regions with saline conditions. Proper mix design and curing duration play an important role in improving resistance to chemical attack, ensuring that the final product can withstand external pressures. Additionally, careful monitoring during the curing process and attention to the quality of constituent materials can lead to enhanced performance over time, ultimately contributing to the longevity and resilience of ferrocement structures in varying conditions.

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