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Examining foundry sand's potential as a partial substitute for m-sand through experimental and numerical research

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ABSTRACT

This study explores the potential of using foundry sand (FS) as a partial replacement for manufactured sand (M Sand) in conventional concrete, aiming to enhance sustainability in construction practices. The experimental program involved creating concrete mixes using ordinary Portland cement (OPC), coarse aggregate (CA), M Sand, and a constant 1% superplasticizer (SP). The control mix consisted of OPC, CA, M Sand, and 1% SP. Subsequent mixes incorporated FS at replacement levels of 5%, 10%, 15%, 20%, 25%, and 30% of the M Sand by weight. The study assessed the workability, compressive strength, and durability of the concrete mixes. Results showed that FS inclusion up to 25% significantly improved the concrete's properties, including enhanced compressive strength and durability, suggesting FS as a viable alternative to M Sand. This research not only promotes the use of industrial byproducts but also addresses environmental concerns related to foundry waste management, contributing to the development of eco-friendly construction materials. By utilizing foundry sand, the construction industry can reduce its reliance on natural sand resources, promoting sustainable practices and reducing the environmental footprint.

Keywords: Foundry sand; Workability; Mechanical property; Durability property; Micro analysis.

1. INTRODUCTION

The construction industry is continuously seeking sustainable alternatives to natural resources due to the increasing rate of urbanization and industrialization. One such substitute for M-sand in concrete is the use of waste foundry sand (WFS), a byproduct of the metal casting industry. From several investigations on the mechanical, long-term, and microstructural characteristics of concrete that contains foundry sand [1]. The research indicates that using WFS can enhance the compressive strength, durability, and overall performance of concrete while also addressing waste management issues [2]. Additionally, WFS has been found to improve the microstructure of concrete, leading to better long-term performance. By utilizing WFS, the construction industry can reduce its reliance on natural sand resources, thereby promoting sustainable practices and minimizing the environmental impact of both sand extraction and industrial waste disposal [3].

The incorporation of foundry sand influences the workability of concrete. The higher replacement levels may necessitate elevated water content to preserve workability, albeit without notably impacting mechanical properties up to a certain threshold. While adjustments in water content are essential to ensure proper mix consistency and placement, careful control can mitigate any adverse effects on the final product's mechanical integrity [4]. By striking a balance between workability and material composition, engineers can harness the benefits of foundry sand as a sustainable alternative in concrete production, without compromising the structural robustness and performance of the end product. Emerging research indicates that the ideal replacement percentage of foundry sand typically falls within the range of 20–30% [5]. At these levels, studies suggest that the physical properties of concrete, including compressive and tensile strengths, are either on par with or marginally superior to those of conventional concrete mixes. This optimal replacement range signifies a balanced integration of foundry sand, maximizing its beneficial effects on concrete performance while minimizing any

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potential drawbacks. By adhering to these recommended replacement levels, engineers can capitalize on the advantageous properties of foundry sand, thereby optimizing the overall strength and durability of concrete structures [6].

Incorporating used foundry sand (UFS) as a partial substitute for fine aggregate in concrete typically leads to a slight enhancement in various mechanical properties. Studies have consistently shown a marginal enrich in compressive strength, splitting tensile strength, and flexural strength when UFS is included in concrete formulations [7]. This improvement underscores the potential of UFS to positively influence the overall performance and structural integrity of concrete elements. By harnessing the beneficial attributes of UFS, engineers can optimize the mechanical properties of concrete while simultaneously addressing environmental concerns associated with its disposal [8]. Many studies have examined the mechanical properties of concrete that contains Waste Foundry Sand (WFS) in place of some of the fine particles. Integrating WFS usually results in a little improvement in modulus of elasticity, splitting tensile strength, and compressive strength [9]. For instance, a study demonstrated that substituting fine aggregate with WFS up to 20% led to mechanical properties akin to the control mix, albeit exhibiting a slight decline in strength performance at higher substitution levels. Additionally, another investigation indicated that concrete formulations containing 10%, 20%, and 30% WFS showcased a slight uptick in strength characteristics, rendering them conducive for high-quality concrete applications [10].

The way reinforced concrete beams that use Waste Foundry Sand (WFS) partially in place of fine aggregate flex. Findings indicate that beams featuring replacement levels of 15%, 25%, and 35% with WFS demonstrate sufficient flexural strength, thereby establishing WFS as a feasible choice for structural applications [11]. Through comprehensive investigations, it has been established that these replacement levels effectively maintain the required flexural performance, ensuring the structural integrity and stability of the concrete beams [12]. Such outcomes signify the potential of WFS as a reliable alternative in the construction industry, offering a sustainable solution without compromising on structural efficiency. By leveraging WFS in reinforced concrete beams, engineers and designers can achieve both performance objectives and sustainability goals, thereby fostering advancements in eco-friendly construction practices [13].

The durability aspect of concrete incorporating Waste Foundry Sand (WFS), revealing promising outcomes. Investigations indicate that integrating WFS can augment the durability properties of concrete [14]. Notably, concrete formulations containing 20% WFS displayed durability characteristics akin to the control mix, devoid of any detrimental environmental repercussions. Moreover, the resilience against chemical assaults, including sodium sulfate and sulfuric acid, was notably enhanced in WFS-infused concrete when juxtaposed with traditional concrete compositions [15]. The potential of WFS as a beneficial additive in bolstering the durability and resilience of concrete structures, thereby contributing to the longevity and sustainability of infrastructure systems. Such insights advocate for the adoption of WFS in concrete production practices, heralding a paradigm shift towards more robust and environmentally conscious construction methodologies [16].

The utilization of waste foundry sand (WFS) as a partial substitute for M-sand in concrete has yielded encouraging findings across multiple domains, including mechanical, durability, and micro-structural properties. Extensive research indicates that integrating WFS into concrete formulations can lead to notable improvements in these key performance metrics [17]. While the optimal replacement level may vary depending on specific factors, such as material characteristics and intended application, a consensus among most studies suggests that incorporating up to 20% WFS as a replacement for M-sand is viable without compromising the overall quality of the concrete [18]. This threshold allows for a substantial reduction in the environmental impact associated with waste foundry sand disposal while simultaneously enhancing the properties of the concrete matrix. Concrete incorporating foundry sand demonstrates commendable durability properties, boasting robust resistance against chloride penetration and sulfate attack [19]. Studies consistently indicate that the inclusion of foundry sand enhances the concrete's ability to withstand these deleterious environmental factors, thereby prolonging its service life and reducing maintenance requirements [20]. Moreover, leveraging foundry sand in concrete production yields a positive environmental impact by repurposing industrial by-products, thereby diverting waste from landfills and reducing the need for virgin materials. While moderate replacement levels (up to 30%) are beneficial, higher levels (above 50%) may lead to a decrease in mechanical properties and workability issues. This sustainable approach aligns with the principles of circular economy and resource conservation, fostering a more eco-friendly construction industry [21].

Concrete incorporating fine waste foundry sand (FWFS) as a partial cement replacement demonstrates enhanced chemical resistance, as evidenced by microstructural analysis. Studies indicate that concrete formulations with higher FWFS content exhibit reduced corrosion when subjected to sodium sulfate and sulfuric acid solutions [22]. This favorable outcome is attributed to the denser microstructure and decreased permeability achieved through FWFS incorporation. The denser matrix effectively mitigates the ingress of aggressive agents, thereby minimizing the potential for chemical deterioration and corrosion of reinforcing materials [23]. The efficacy of FWFS as a supplementary material in enhancing the chemical durability of concrete structures, paving the way for its utilization in environments prone to chemical exposure [24].

Understanding the internal makeup and behavior of concrete mixes requires a thorough understanding of microstructural studies. X-ray diffraction (XRD), scanning electron microscopy (SEM), and energy dispersive X-ray spectroscopy (EDS) are a few of the sophisticated methods that have been used in numerous studies to examine the complex microstructural characteristics of concrete that contains foundry sand. XRD enables researchers to identify crystalline phases present in the concrete matrix, shedding light on its mineralogical composition [25]. SEM provides high-resolution images of the concrete microstructure, allowing for the observation of particle morphology and interfacial characteristics. EDS further complements SEM by facilitating elemental analysis, thereby elucidating the distribution and concentration of various components within the concrete [26]. The study used scanning electron microscopy (SEM) and X-ray diffraction (XRD) to examine the microstructure of concrete that included a 20% substitution of waste foundry sand (WFS). The findings demonstrated that the incorporation of WFS did not induce significant alterations in the crystalline phases of the concrete, as evidenced by XRD analysis [27]. However, SEM imaging revealed a denser microstructure with fewer voids in the WFS-incorporated concrete specimens, indicating an enhancement in packing density. This densification suggests that the inclusion of WFS promotes a more compact arrangement of particles within the concrete matrix, potentially leading to improved mechanical properties and durability [28].

In the experiment, concrete specimens with up to a 25% substitution of Waste Foundry Sand (WFS) underwent X-ray Diffraction (XRD) and Energy Dispersive X-ray Spectroscopy (EDS) investigations [29]. The results revealed that the inclusion of WFS did not introduce any deleterious phases into the concrete matrix. Moreover, the microstructural examination indicated that the presence of WFS had minimal impact on the concrete's internal composition and morphology, particularly up to a 20% replacement level [30]. The WFS can be incorporated into concrete mixes at moderate replacement levels without significantly altering the microstructural characteristics compared to the control mix. Such findings provide valuable insights into the compatibility of WFS with concrete matrices, affirming its potential as a sustainable additive for improving the performance and durability of concrete. The utilization of treated used foundry sand (TUFS) in concrete significantly impacts its microstructural properties [31]. Acid treatment of used foundry sand (UFS) enriches the silica content, thereby fostering a more homogeneous and compact microstructure within the concrete matrix. This enhanced homogeneity and densification contribute to improved mechanical strength and durability of the concrete. Additionally, the acid treatment process effectively reduces the iron content present in UFS, which could otherwise impede the binding properties of the concrete [32]. By minimizing the iron content, the treatment process ensures better compatibility between TUFS and the cementitious matrix, resulting in enhanced cohesion and adhesion within the concrete. Overall, the acid treatment of UFS plays a pivotal role in optimizing the microstructural properties of concrete [33].

The incorporation of used foundry sand (UFS) in concrete mixtures has been observed to result in a slight enhancement of strength properties. Microstructural analysis has revealed that UFS particles are effectively integrated within the cement matrix, promoting the overall integrity of the concrete. This integration facilitates improved cohesion and interlocking between the particles, thereby enhancing the mechanical performance of the concrete [34].

2. MATERIALS

Understanding each material's unique qualities and how they affect the overall performance of the concrete mix is crucial when analyzing the physical attributes of the various components used to produce concrete. Let's delve into the physical properties of cement, M-Sand, coarse aggregate, Glenium Stream 2, and foundry sand. The cement, specifically Ordinary Portland Cement (OPC) Grade 53, its physical properties are indicative of high-quality material suitable for structural applications. OPC 53 has a surface area of 2259 cm^2/gm, which signifies a finely ground product, enhancing its reactivity with water, leading to quicker setting times and higher early strength. The relative density of 3.15 suggests it is heavier compared to other materials in the mix, contributing to the overall density of concrete. Its grey color and powdered form are standard for cement, while the particle size being less than 90 microns ensures a uniform mixture. The volumetric expansion is limited to 3 mm, which is within acceptable limits, ensuring minimal dimensional changes post-setting, thus contributing to the stability and durability of structures.

M-Sand, or manufactured sand, is another critical component in concrete. Its physical properties make it a suitable replacement for natural sand. The appearance of M-Sand is grainy, and it has a relative density of 2.63, slightly less dense than cement but adequate for maintaining the structural integrity of the mix. The apparent density is 15.5 gm/cc, indicating its compactness when settled. Grey in color, M-Sand has a water absorption rate of 6.13%, highlighting its ability to retain moisture, which can affect the water-cement ratio in the mix. The dampness level of 1.55% is relatively low, ensuring minimal influence on the moisture content of the overall mixture. Classified under Zone II, M-Sand has a maximum grain size of 1.18 mm and a fineness modulus of 4.666, ensuring an optimal balance between fineness and coarseness for good workability and compaction.

Coarse aggregates are vital for providing bulk and strength to concrete. Their relative density of 2.748 makes them denser than both cement and M-Sand, contributing significantly to the concrete's overall mass and strength. The apparent density of 2.49 g/cc suggests they are compact when in a loose state. Coarse aggregates have an absorption rate of 1%, meaning that they have little effect on the amount of water required by the concrete mixture. The absence of surface moisture ensures no additional water is introduced into the mix. The aggregate impact value of 13.64% indicates their resistance to sudden impacts or loads, which is essential for durable concrete. The fineness modulus of 6 and an angular shape with a maximum size of 20 mm ensure good interlocking and load distribution within the concrete matrix.

Glenium Stream 2 is a superplasticizer used to improve the workability of concrete. It is colorless and in liquid form, with a specific gravity of 1.01, slightly denser than water, making it easy to mix with other components. Its pH value of greater than 6 ensures it is mildly alkaline, compatible with cement chemistry. The chloride iron content is less than 0.18%, which is low enough to prevent corrosion of steel reinforcement.

Foundry sand, a type of fine sand, has specific properties that can affect the concrete mix. With a bulk density of 1779 kg/m^3 and a fineness modulus of 2.73, foundry sand is moderately fine, suitable for filling voids and improving the workability of the concrete. Its moisture content of 0.471% is low, which minimizes the risk of excess water in the mix. Spherical in shape and classified as Zone III, foundry sand has a specific gravity of 2.53, making it lighter than the aggregates but suitable for improving the flow and compaction of the concrete. The water absorption rate of 1% indicates its limited impact on the water content of the concrete mix.

In summary, each of these materials, with their distinct physical properties, plays a crucial role in the concrete mix. The combination of OPC 53 cement, M-Sand, coarse aggregates, Glenium Stream 2, and foundry sand results in a well-balanced concrete mixture with optimized strength, durability, and workability. Understanding these properties helps in designing concrete mixes that meet specific structural and performance requirements.

3. METHODOLOGY

This study explores the effects of incorporating foundry sand (FS) as a partial replacement for manufactured sand (M-Sand) in concrete mixtures, examining the physical and mechanical properties of the resulting concrete. Seven concrete mixtures are prepared, varying the FS content from 0% to 30% in increments of 5%, with corresponding adjustments to the M-Sand content. For each mix, dry materials are thoroughly blended before the gradual addition of water and superplasticizer, ensuring a homogenous mix. The workability of each concrete mix is assessed using a slump test, ensuring that the superplasticizer dosage achieves the desired consistency.

Concrete specimens are cast in standard molds for testing compressive, tensile, and flexural strengths. These specimens are cured in water tanks at 25°C until the testing age. Compressive strength tests are conducted on 150mm cubic specimens at 7, 14, and 28 days, while splitting tensile strength tests are performed on cylindrical specimens (150mm diameter) at similar intervals. Additionally, flexural strength tests are conducted to evaluate the performance of the concrete under bending stresses. The durability qualities of ordinary concrete and foundry sand as a partial substitute for M-sand in concrete are also investigated. X-ray diffraction (XRD) and scanning electron microscopy (SEM) are used in microstructural studies to evaluate how well FS particles are integrated into the cement matrix. This study aims to determine the optimal FS replacement level that maintains or enhances the mechanical properties of concrete while offering a sustainable solution for utilizing industrial by-products in construction materials.

4. RESULTS AND DISCUSSION

4.1. Slump cone test

The results from the slump test for various concrete mixes with different percentages of foundry sand (FS) replacing manufactured sand (M-Sand) are presented in the table. The conventional concrete mix (M1) showed a slump of 117 mm, indicating its workability. As the percentage of FS increased from 0% to 30%, a general decrease in slump values was observed. For mix M2, with 0% FS and 100% M-Sand, the slump increased to 126 mm, suggesting improved workability due to the 1% superplasticizer (SP). As FS content increased to 5% (M3) and 10% (M4), the slump values decreased to 122 mm and 119 mm, respectively. This reduction can be attributed to the different physical properties of FS compared to M-Sand, which affects the water demand and flow characteristics of the mix. Further increases in FS content to 15% (M5) and 20% (M6) resulted in slump values of 116 mm and 112 mm, respectively. The decrease in workability continues as FS content reaches 25% (M7) and 30% (M8), with slump values dropping to 108 mm and 103 mm. This trend indicates that higher FS content makes the mix stiffer, likely due to the finer particles and increased surface area of FS, which demand more water to achieve the same level of workability as M-Sand. Overall, while the inclusion of FS as a partial replacement for M-Sand slightly reduces the workability of the concrete mix, the use of superplasticizer helps to maintain acceptable slump values across all mixes. Figure 1 shows the slump cone test.

4.2. Compaction factor test

The results from the compaction factor test for various concrete mixes incorporating different percentages of foundry sand (FS) as a replacement for manufactured sand (M-Sand) are provided in the table. The conventional concrete mix (M1) exhibited a compaction factor of 0.89, serving as the baseline for comparison. For mix M2, which contains 0% FS and 100% M-Sand with 1% superplasticizer (SP), the compaction factor increased to 0.93. This improvement in compaction factor suggests that the addition of SP significantly enhances the workability and compaction of the mix. As FS content increased to 5% (M3) and 10% (M4), the compaction factors slightly decreased to 0.91 and 0.89, respectively. These values indicate that while the replacement of M-Sand with FS marginally affects the compaction, the overall workability remains relatively high.

The increases in FS content to 15% (M5) and 20% (M6) resulted in compaction factors of 0.88 and 0.86, respectively. The downward trend continued as FS content was increased to 25% (M7) and 30% (M8), with compaction factors dropping to 0.84 and 0.83, respectively. This progressive reduction in the compaction factor with higher FS content suggests a decrease in workability and ease of compaction. The finer particles and increased surface area of FS require more water to achieve the same workability, thus affecting the compaction factor. Overall, while the inclusion of FS as a partial replacement for M-Sand slightly reduces the compaction factor, the use of SP helps maintain acceptable compaction levels across all mixes. The observed trend underscores the importance of balancing FS content and SP dosage to ensure that the concrete mix remains workable and compactable. Figure 2 compaction factor test.

4.3. Compressive strength test

The compressive strength of various concrete mixes, including conventional concrete (M1) and mixes with varying percentages of foundry sand (FS) and manufactured sand (M Sand). Conventional concrete (M1) has a 28-day compressive strength of 26.69 MPa. Mix M2, which has 100% OPC and 100% M Sand, shows a slight improvement with 27.57 MPa. As foundry sand is introduced in Mix M3 (5% FS), there is a notable increase in strength to 28.95 MPa. The trend continues with Mix M4 (10% FS) achieving 30.83 MPa, and Mix M5 (15% FS) reaching 32.90 MPa at 28 days. Mixes M6 (20% FS), M7 (25% FS), and M8 (30% FS) show even higher

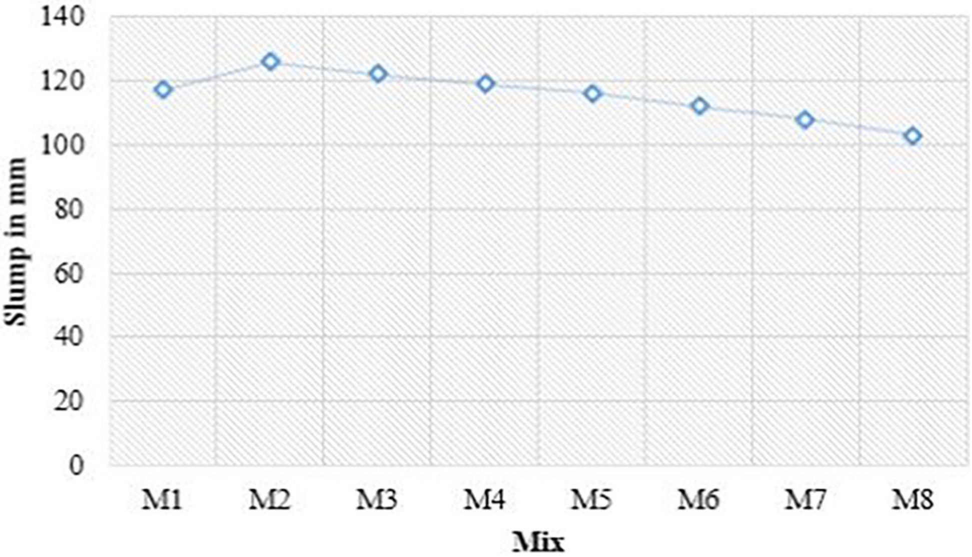

Figure 1: Slump cone test results.

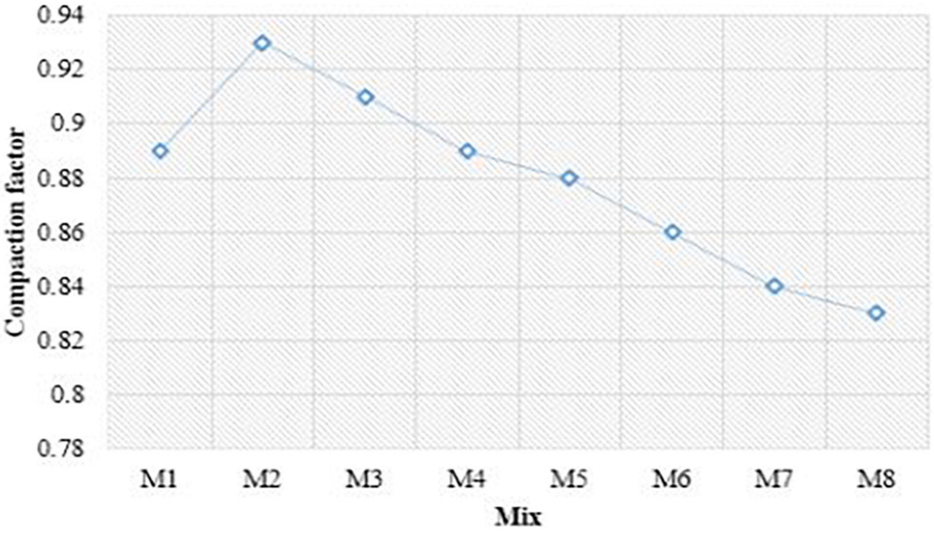

Figure 2: Compaction factor test results.

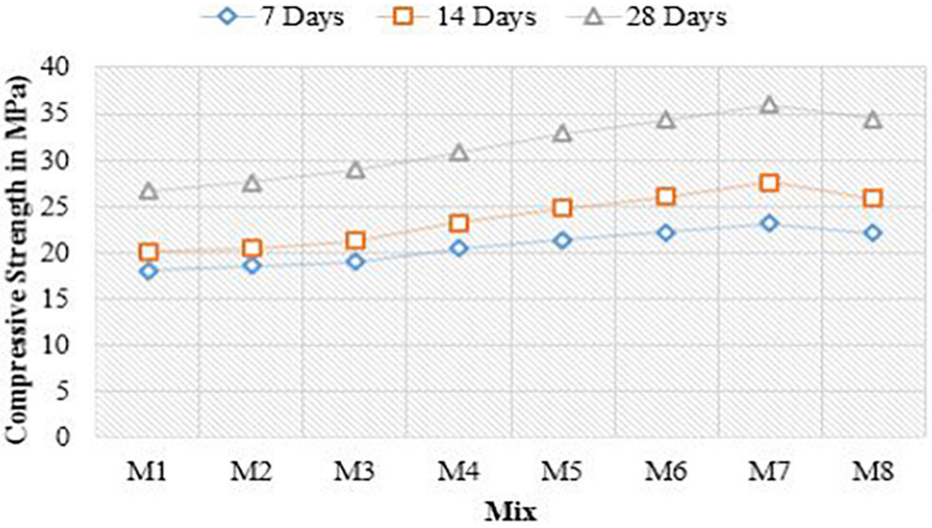

Figure 3: Compressive strength.

compressive strengths, with M7 reaching the highest strength of 35.98 MPa. The increasing trend indicates that incorporating foundry sand up to 30% in the mix enriches the compressive strength of concrete significantly. The data suggests that foundry sand enhances the compressive strength of concrete mixes, with the highest improvement observed at 25% FS. This enhancement can be attributed to the fine particles of foundry sand filling voids in the concrete matrix, leading to denser and stronger concrete. Thus, utilizing up to 25–30% foundry sand in concrete mixes is beneficial for achieving higher compressive strength. Figure 3 compressive strength test.

4.4. Split tensile strength test

The split tensile strength of various concrete mixes, including conventional concrete (M1) and mixes with varying percentages of foundry sand (FS) and manufactured sand (M Sand). Conventional concrete (M1) has a 28-day split tensile strength of 3.59 MPa. Mix M2, which has 100% OPC and 100% M Sand, shows a slight improvement with 3.67 MPa. As foundry sand is introduced in Mix M3 (5% FS), there is a notable increase in strength to 3.75 MPa. The trend continues with Mix M4 (10% FS) achieving 3.88 MPa, and Mix M5 (15% FS) reaching 3.92 MPa at 28 days. Mixes M6 (20% FS), M7 (25% FS), and M8 (30% FS) show even higher split tensile strengths, with M7 reaching the highest strength of 4.00 MPa. The increasing trend indicates that incorporating foundry sand up to 25% in the mix enriches the split tensile strength of concrete significantly.

The data suggests that foundry sand enhances the split tensile strength of concrete mixes, with the highest improvement observed at 25% FS. This enhancement can be attributed to the fine particles of foundry sand filling voids in the concrete matrix, leading to denser and stronger concrete. Thus, utilizing up to 25% foundry sand in concrete mixes is beneficial for achieving higher split tensile strength. Figure 4 split tensile strength.

4.5. Flexural strength test

The flexural strength of various concrete mixes, including conventional concrete (M1) and mixes with varying percentages of foundry sand (FS) and manufactured sand (M Sand). Conventional concrete (M1) has a 28-day flexural strength of 4.26 MPa. Mix M2, which has 100% OPC and 100% M Sand, shows a significant improvement with 5.33 MPa. As foundry sand is introduced in Mix M3 (5% FS), there is a further increase in strength to 5.40 MPa. The trend continues with Mix M4 (10% FS) achieving 5.51 MPa, and Mix M5 (15% FS) reaching 6.01 MPa at 28 days. Mixes M6 (20% FS), M7 (25% FS), and M8 (30% FS) show even higher flexural strengths, with M7 reaching the highest strength of 6.56 MPa. The increasing trend indicates that incorporating foundry sand up to 25% in the mix significantly enriches the flexural strength of concrete. The data suggests that foundry sand enhances the flexural strength of concrete mixes, with the highest improvement observed at 25% FS. This enhancement can be attributed to the fine particles of foundry sand filling voids in the concrete matrix, leading to denser and stronger concrete. Thus, utilizing up to 25% foundry sand in concrete mixes is beneficial for achieving higher flexural strength. Figure 5 flexural strength test.

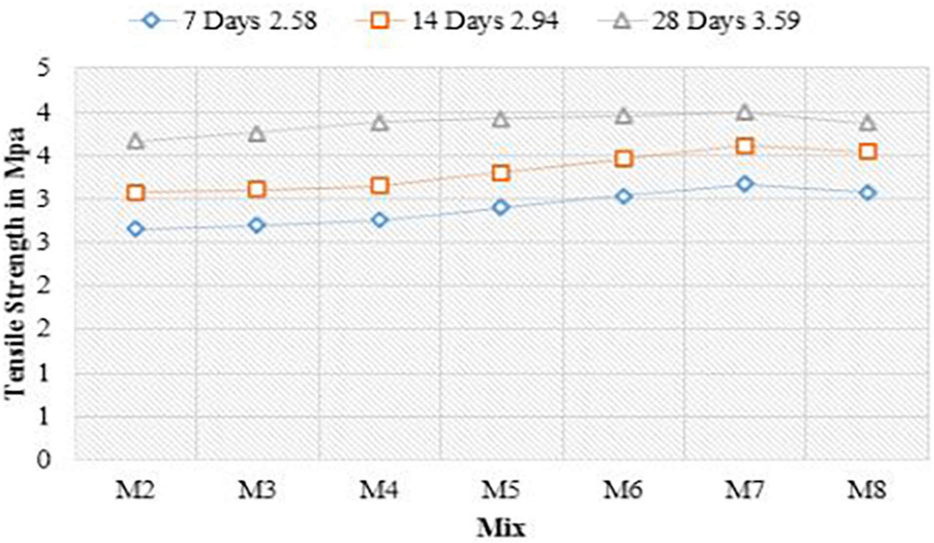

Figure 4: Split tensile strength.

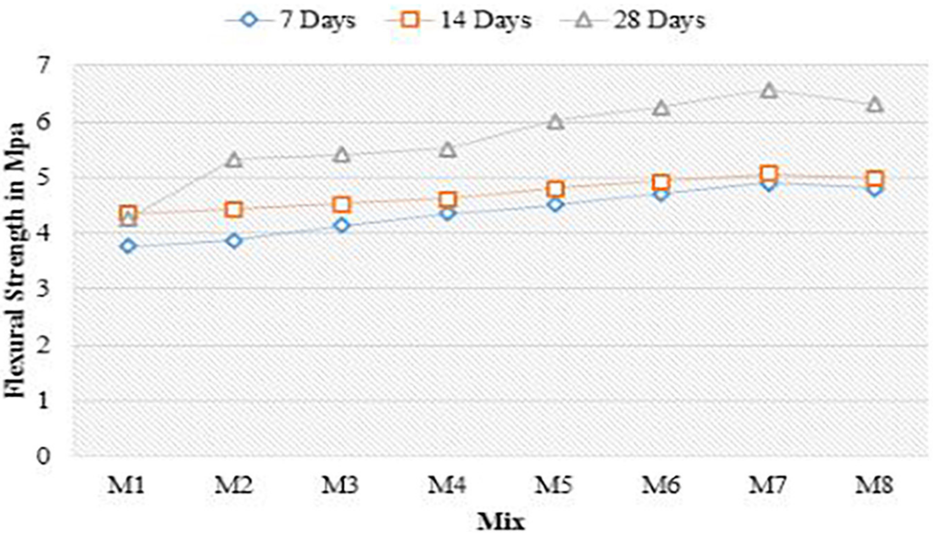

Figure 5: Flexural strength.

4.6. Saturated water absorption test

The saturated water absorption test results for various concrete mixes, including conventional concrete (M1) and mixes with varying percentages of foundry sand (FS) and manufactured sand (M Sand). Conventional concrete (M1) has a 28-day water absorption of 2.32%, which decreases to 2.18% at 56 days and 2.06% at 90 days. Mix M2, with 100% OPC and 100% M Sand, shows slightly lower absorption rates of 2.29%, 2.15%, and 2.04% at 28, 56, and 90 days, respectively. As foundry sand is introduced in Mix M3 (5% FS), there is a further reduction in water absorption to 2.25%, 2.13%, and 2.02% over the same periods. The trend continues with Mix M4 (10% FS) achieving even lower values of 2.19%, 2.10%, and 2.00%. Mix M5 (15% FS) shows the most significant reduction, with water absorption rates of 2.15%, 2.07%, and 1.97%. Mixes M6 (20% FS), M7 (25% FS), and M8 (30% FS) show varied absorption rates, with M6 reaching 1.93% at 90 days, the lowest among all mixes. However, M7 and M8 have slightly higher values at 1.96% and 2.00% at 90 days, respectively. The data indicates that incorporating foundry sand up to 20% reduces the water absorption of concrete mixes, enhancing their durability. The reduction in water absorption can be attributed to the finer particles of foundry sand, which fill voids in the concrete matrix, reducing porosity and making the concrete more impermeable. Thus, utilizing up to 20% foundry sand in concrete mixes is beneficial for improving resistance to water absorption. Figure 6 shows the saturated water absorption test.

4.7. Acid resistance test

The percentage loss of weight in the sulfuric acid resistance test for various concrete mixes, including conventional concrete (M1) and mixes with varying percentages of foundry sand (FS) and manufactured sand (M Sand). Conventional concrete (M1) shows a 3.18% weight loss at 28 days, which decreases to 2.99% at 56 days and 2.39% at 90 days. Mix M2, with 100% OPC and 100% M Sand, has slightly lower weight losses of 3.16%, 2.96%, and 2.36% over the same periods, respectively. As foundry sand is introduced in Mix M3 (5% FS), there is a further reduction in weight loss to 3.13%, 2.94%, and 2.34% at 28, 56, and 90 days, respectively. This trend continues with Mix M4 (10% FS), which achieves weight losses of 3.12%, 2.92%, and 2.31%. Mix M5 (15% FS) shows a more significant reduction, with weight losses of 3.10%, 2.89%, and 2.30%. Mix M6 (20% FS) has the lowest weight loss values of 3.08%, 2.86%, and 2.26% at 28, 56, and 90 days, respectively. Mixes M7 (25% FS) and M8 (30% FS) show slightly higher values compared to M6, indicating an optimal foundry sand content around 20% for minimizing weight loss in sulfuric acid. The data suggests that incorporating foundry sand up to 20% in concrete mixes improves resistance to sulfuric acid, as evidenced by the reduced weight loss over time. The improved acid resistance can be attributed to the fine particles of foundry sand filling the voids in the concrete matrix, thereby reducing permeability and enhancing durability. Thus, utilizing up to 20% foundry sand in concrete mixes is recommended for achieving better acid resistance. Figure 7 shows the percentage of weight loos in acid resistance test.

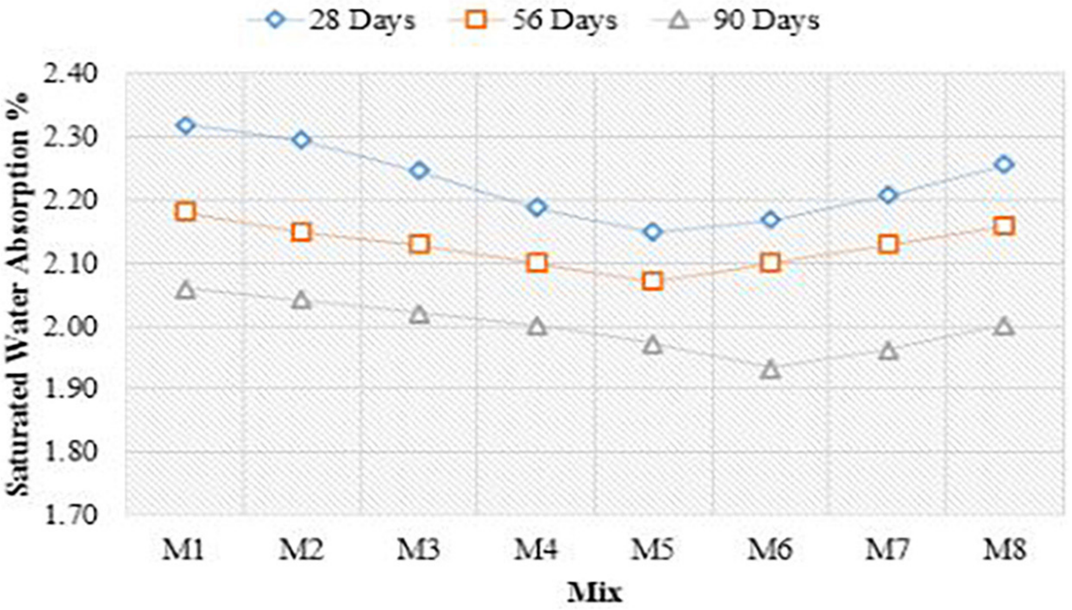

Figure 6: Saturated water absorption.

4.8. EDAX

The Energy Dispersive X-ray Analysis (EDAX) test results reveal the elemental composition of untreated foundry sand, highlighting its suitability as a partial replacement for M-sand in concrete applications. The predominant component is Silicon Dioxide (SiO_2), constituting 70.08% of the sand, confirming its primary silica composition which is crucial for structural integrity. Sodium Oxide (Na_2O) is also significantly present at 15.13%, influencing the chemical reactivity and melting behavior of the sand. Aluminum Oxide (Al_2O_3), at 3.97%, contributes to the refractory properties, enhancing resistance to high temperatures. Iron Oxide (FeO) accounts for 3.20%, affecting the color and melting characteristics. Minor components like Magnesium Oxide (MgO) at 0.29%, Potassium Oxide (K_2O) at 0.15%, and trace amounts of Sulfur Trioxide (SO_3) at 0.07% and Titanium Dioxide (TiO_2) at 0.23% contribute to the overall mineralogy. Additionally, Strontium Oxide (SrO) at 1.74% may influence the physical and chemical properties, particularly in high-temperature environments. These results provide a comprehensive chemical profile of the foundry sand, confirming its potential as a structural component in concrete. The high SiO_2 content ensures strength, while the presence of other oxides offers insights into additional properties that could enhance the performance of concrete mixes. Figure 8 and 9 shows the EDAX image of M1 mix and M7 mix.

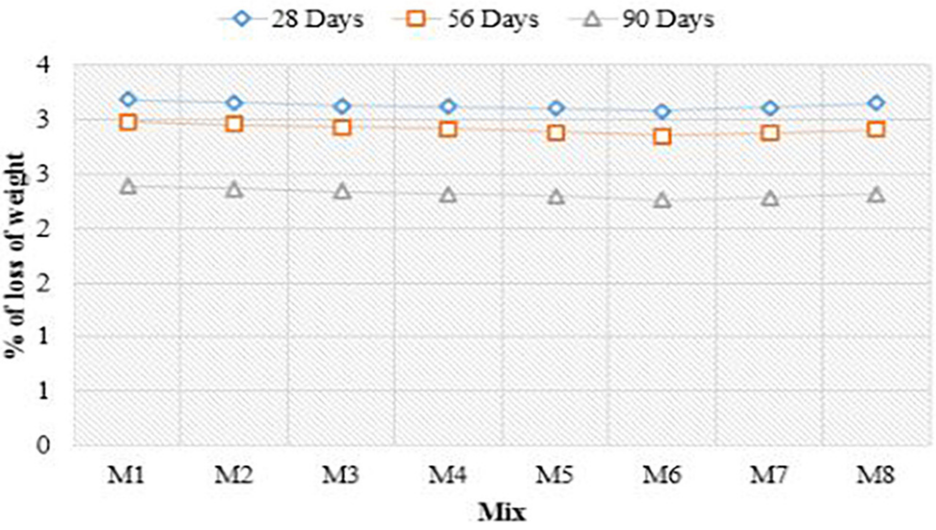

Figure 7: Acid resistance test.

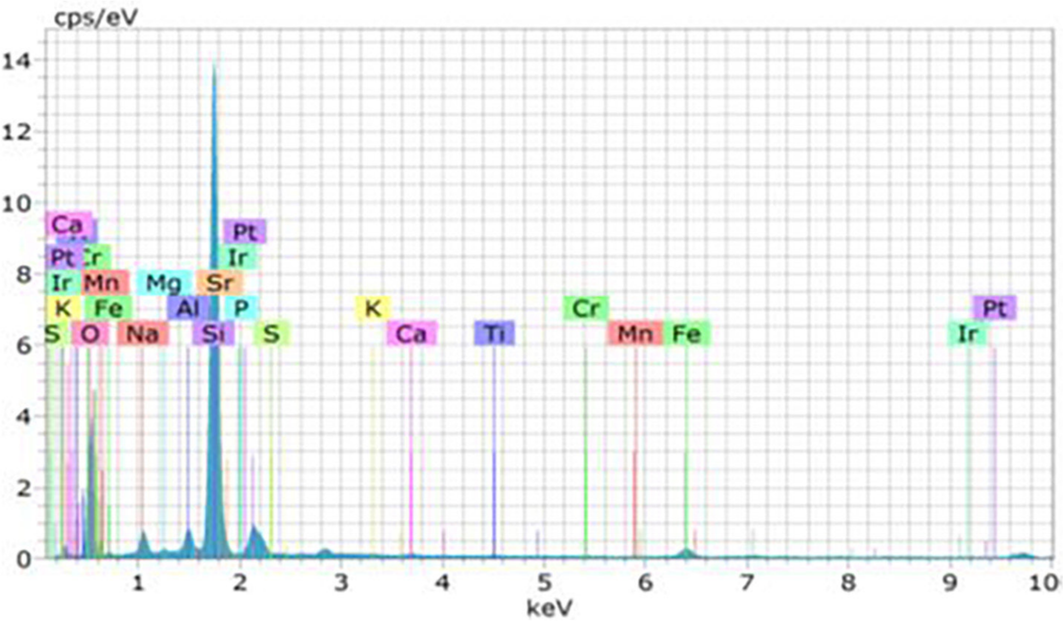

Figure 8: EDAX for M1 mix.

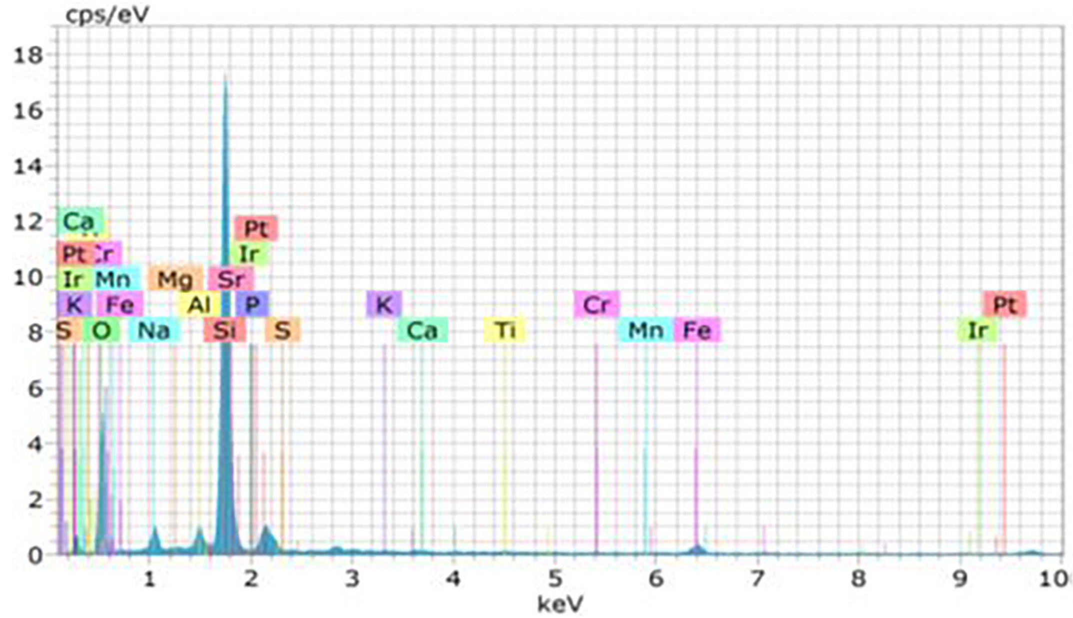

Figure 9: EDAX for M7 mix.

5. NUMERICAL APPROACH

5.1. Compressive strength test

The ANOVA test results highlight significant variations in the compressive strength of different concrete mixes over time. The analysis shows that the factor "Days" (time) has a substantial impact on compressive strength, with an F-value of 34.387 and a P-value of 9.07E-08. This indicates that the differences in compressive strength observed at various time intervals (7, 14, 28, 56, and 90 days) are statistically significant. Similarly, the mix composition, specifically the inclusion of foundry sand (FS) and manufactured sand (M Sand), also significantly influences the compressive strength. The "Compressive Strength" factor yielded an F-value of 385.136 and an extremely low P-value of 5.78E-13, demonstrating that the variations between different concrete mix compositions are statistically significant. The error term, representing unexplained variation within the samples, had a relatively low sum of squares (9.08), indicating that most of the variation in compressive strength is well-accounted for by the time and mix composition factors. The critical F-values for both factors are lower than the calculated F-values, further confirming their significance. In conclusion, curing time and mix composition—specifically, the ratios of OPC, FS, and M Sand—have a major impact on the compressive strength of concrete. These results highlight how crucial it is to optimize the curing time as well as the mix design in concrete applications in order to attain the appropriate strength properties. The compressive strength test results from the ANOVA are displayed in Table 1.

5.2. Split tensile strength

The analysis of variance (ANOVA) Table 2 presented reveals the sources of variation in a dataset, shedding light on factors influencing the outcome. In this particular study, the impact of both the number of days and split tensile strength (measured in MPa) on the observed results is evident. The variation attributed to the number of days showcases its significance, as indicated by a remarkably low p-value (2.13834E-06), suggesting a substantial influence on the outcome. Similarly, the split tensile strength demonstrates a significant effect, with an even lower p-value (1.3721E-12), emphasizing its crucial role in determining the outcome. However, it's essential to acknowledge the presence of unexplained variability represented by the error term, which accounts for random fluctuations not captured by the analyzed factors. This comprehensive understanding of the sources of variation allows researchers to make informed interpretations and draw meaningful conclusions regarding the factors impacting the observed phenomenon. By identifying and quantifying the influence of these variables, researchers can refine their hypotheses, optimize experimental designs, and potentially guide interventions or improvements in relevant processes or systems.

5.3. Flexural strength test

The provided ANOVA Table 3 delineates the sources of variation within a dataset, offering insights into factors impacting the observed outcomes. In this analysis, both the number of days and fleural strength (measured in MPa) emerge as significant contributors to the variability. The variation linked to the number of days is substantial, as evidenced by a low p-value (0.000184133), indicating its considerable influence on the outcome. Similarly, fleural strength demonstrates a significant effect, with an even lower p-value (2.22719E-07), underscoring its importance in determining the observed results. However, it's crucial to acknowledge the presence of unexplained variability denoted by the error term, accounting for random fluctuations not explained by the analyzed factors. This comprehensive understanding of the sources of variation enables researchers to make informed interpretations and draw meaningful conclusions regarding the factors influencing the phenomenon under study. By identifying and quantifying the impact of these variables, researchers can refine their hypotheses, optimize experimental designs, and potentially inform interventions or enhancements in relevant processes or systems.

5.4. Saturated water absorption test

The ANOVA Table 4 provided offers insights into the sources of variation within a dataset, elucidating factors influencing the observed outcomes. In this analysis, both the number of days and the percentage of saturated water absorption stand out as significant contributors to the variability. The variation associated with the number of days is notable, evidenced by a low p-value (4.88891E-05), indicating its substantial impact on the outcome.

Table 1: ANOVA for compressive strength test.

SOURCE OF VARIATION	SS	DF	MS	F	P-VALUE	F CRIT
Days	156.0602	7	22.29431	34.38735	9.07E-08	0.951605
Compressive Strength (MPa)	499.3889	2	249.6945	385.1355	5.78E-13	0.728627
Error	9.076604	14	0.648329	–	–	–
Total	664.5257	23	272.6371	419.5229	9.07E-08	1.680231

Table 2: ANOVA for split tensile strength test.

SOURCE OF VARIATION	SS	DF	MS	F	P-VALUE	F CRIT
Days	0.819261	7	0.117037	20.91856	2.14E-06	0.951605
Split Tensile Strength (MPa)	3.799417	2	1.899709	339.5429	1.37E-12	0.728627
Error	0.078329	14	0.005595	–	–	–
Total	4.697006	23	2.022341	360.4615	2.14E-06	1.680231

Table 3: ANOVA for flexural strength test.

SOURCE OF VARIATION	SS	DF	MS	F	P-VALUE	F CRIT
Days	4.69829	7	0.671184	9.780729	0.000184	0.951605
Fleural Strength (MPa)	7.608054	2	3.804027	55.43359	2.23E-07	0.728627
Error	0.960724	14	0.068623	–	–	–
Total	13.26707	23	4.543834	65.21432	0.000184	1.680231

Table 4: ANOVA for saturated water absorption test.

SOURCE OF VARIATION	SS	DF	MS	F	P-VALUE	F CRIT
Days	0.040604	7	0.005801	12.39681	4.89E-05	0.951605
Saturated Water Absorption %	0.210802	2	0.105401	225.2593	2.26E-11	0.728627
Error	0.006551	14	0.000468	–	–	–
Total	0.257957	23	0.111669	237.6561	4.89E-05	1.680231

Table 5: ANOVA for acid resistance test.

SOURCE OF VARIATION	SS	DF	MS	F	P-VALUE	F CRIT
Days	0.031771	7	0.004539	38.17028	4.59E-08	0.951605
% Loss of Weight in Acid resistance test	2.810677	2	1.405339	11818.89	2.55E-23	0.728627
Error	0.001665	14	0.000119	–	–	–
Total	2.844113	23	1.409996	11857.06	4.59E-08	1.680231

Similarly, the percentage of saturated water absorption demonstrates a highly significant effect, with an even lower p-value (2.25878E-11), underscoring its importance in determining the observed results. However, it's important to acknowledge the presence of unexplained variability denoted by the error term, accounting for random fluctuations not accounted for by the analyzed factors. This comprehensive understanding of the sources of variation empowers researchers to make informed interpretations and draw meaningful conclusions regarding the factors influencing the phenomenon under study. By identifying and quantifying the impact of these variables, researchers can refine their hypotheses, optimize experimental designs, and potentially inform interventions or enhancements in relevant processes or systems.

5.5. Acid resistance test

The ANOVA Table 5 provided offers a comprehensive breakdown of the sources of variation within the dataset, shedding light on factors influencing the observed outcomes. In this analysis, both the number of days and the percentage loss of weight in the acid resistance test emerge as significant contributors to the variability. The variation attributed to the number of days is substantial, evidenced by a notably low p-value (4.59062E-08), indicating its considerable impact on the outcome. Similarly, the percentage loss of weight in the acid resistance test demonstrates an extremely significant effect, with an even lower p-value (2.54595E-23), underscoring its critical role in determining the observed results. However, it's important to acknowledge the presence of unexplained variability denoted by the error term, accounting for random fluctuations not captured by the analyzed factors. This comprehensive understanding of the sources of variation empowers researchers to make informed interpretations and draw meaningful conclusions regarding the factors influencing the phenomenon under study. By identifying and quantifying the impact of these variables, researchers can refine hypotheses, optimize experimental designs, and potentially inform interventions or enhancements in relevant processes or systems.

6. CONCLUSION

This study delved into the feasibility of utilizing foundry sand as a partial replacement for M-sand, employing both experimental investigations and a numerical approach. Through a systematic exploration, the research aimed to contribute to sustainable construction practices by repurposing waste materials and reducing environmental impacts associated with traditional sand usage. The experimental work involved comprehensive testing to evaluate the performance of concrete mixes incorporating varying proportions of foundry sand in lieu of M-sand. Results indicated promising outcomes, with the concrete specimens exhibiting satisfactory mechanical properties and durability characteristics. Notably, the incorporation of foundry sand yielded comparable or even superior performance in certain aspects, highlighting its potential as a viable alternative in concrete production.

Complementing the experimental findings, a numerical approach was employed to model the behavior of the concrete mixes at a theoretical level. This computational analysis provided valuable insights into the underlying mechanisms governing the interaction between foundry sand particles and the cementitious matrix. The numerical simulations improved our understanding of the structural performance and durability of the concrete compositions by modeling the behavior of the material under various conditions. All things considered, the amalgamated empirical and computational studies present a comprehensive viewpoint regarding the application of foundry sand in the manufacturing of concrete. The results highlight the potential advantages and technical viability of using foundry sand as a partial replacement for M-sand. Additionally, the study adds to the expanding corpus of research on waste use and sustainable material development in the building sector.

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