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A Comprehensive Review on the Performance of Steel Fiber Reinforced Metakolin Concrete

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ABSTRACT

The paper presents a review of studies investigating the performance of steel fiber-reinforced metakaolin concrete. Metakaolin, a pozzolanic material, is used as a partial replacement for cement in the concrete mix, and steel fibers are added to improve the tensile strength and ductility of the material. The review covers various aspects such as the effect of steel fiber content, aspect ratio, and orientation on the mechanical properties of the concrete. The paper also discusses the durability performance of steel fiber-reinforced metakaolin concrete in terms of resistance to abrasion, and corrosion. Additionally, the review highlights the material's potential applications in various construction sectors. The addition of steel fibers to metakaolin concrete improves its mechanical properties, and the material exhibits good durability performance.The paper concludes that steel fiber-reinforced metakaolin concrete is a promising material for use in a range of construction applications, but further research is needed to optimize its properties and develop guidelines for its use.

Keywords*:Steel Fiber Reinforced Concrete (SFRC), Metakaolin (MK), Steel Fibre (SF), Metakaolin Mix Steel Fibre Concrete (MKSFC),* Mechanical Properties.

1. Introduction

Steel Fiber Reinforced Metakaolin Concrete (SFMRC) is an emerging construction material due to its improved properties over traditional concrete, such as increased ductility, increased tensile strength, and improved durability. This paper states the performance of SFMRC and discusses the advantages, disadvantages, and potential applications of this material. Initially, the focus is to discuss the properties of SFMRC, including its composition, mechanical properties, and durability. Later, the performance tests and analyses that have been conducted on SFMRC, including flexural and compressive strength tests, fracture toughness tests, and fatigue tests. Finally, the paper concludes the potential applications of SFMRC and outlines future directions of research that can be undertaken to further improve the performance of this material.

1.1. Fiber Reinforced Concrete (FRC)

Fiber Reinforced Concrete (FRC) is a composite material made up of concrete and an assortment of reinforcing fibers. It is designed to increase the strength and durability of concrete while decreasing its susceptibility to cracking and spalling. FRC is used in a variety of structural applications, from bridges and highways to foundations and tunnels. It is also used in non-structural applications, such as flooring and paving. FRC has the potential to revolutionize the construction industry, as it is more resistant to cracking and spalling, more durable, and more cost effective than traditional concrete.Concrete's mechanical properties are affected by the combination of steel fiber and metakaolin together. steel fiber reinforced concrete mixtures; Portland cement was partially replaced with MK as 10% by weight of the total binder content.

Two kinds of hook-ended steel fibers were used, with length/aspect ratios of 60/80 and 30/40 to develop the metakaolin. The water-to-binder ratios (w/b) for two series of concrete groups were 0.35 and 0.50. produce fiber reinforced concretes. High-strength concrete (HSC) is distinct from conventional

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concrete, thereby popularizing HSC concrete in a large variety of applications in the construction industry. Used for high-rise buildings, HSC avoids the unacceptable oversized columns on the lower floors, allowing large column spacing and usable floor space, or increasing the number of possible stories without detracting from lower floors [1]. Buildings and structures made of concrete benefit from the uniformly high density and extremely low impermeability of HSC, which gives it excellent resistance to hostile environments and disintegrating agencies [2,3]. the effect of steel fibers and silica fume on HSC's strength, showing that the fiber volume and aspect ratio controlled the concrete's compressive strength.

According to Chunxiang and Patnaikuni [4], the compressive strength of HSFRC increased with maturation, rising by 24% in the HSFRC that was 76 days old. According to Marar et al. [5], at each fiber aspect ratio, the compressive strength of HSFRC improved with the increase in fiber volume. And as far as Daniel and Loukili [6] declared, the compressive strength of HSFRC held 15% advantage over its HSC partner. Fiber-reinforced concrete (FRC) can continue to withstand heavy weights even when it deflects. The features of the matrix as well as the type of fiber, its concentration, its geometry, its orientation, and its dispersion all affect the traits and efficacy of FRC [7]. Researchers have long documented the mechanical characteristics of some pozzolanic materials, especially their crushing strength [8–14]. Adding metakaolin (MK) as an additional cementing component to concrete can improve the material's characteristics. The production of MK, an ultrafine pozzolana, involves heating purified kaolin clay to temperatures between 650 and 900 C in order to calcine the water that has been chemically bonded to it and break its crystalline structure [18–19]. high-reactivity in terms of mechanicalcharacteristics, permeability, and longevity qualities, MK exhibits similar performance to those with other mineral admixtures [20–28]. Additionally, this substance is ecologically friendly because it uses less Portland cement, reducing CO2 emissions into the atmosphere.

1.2. SteelFiberMetakolin Concrete (SFMC)

Steel fiber-reinforced metakaolin concrete is a type of concrete that incorporates steel fibers and metakaolin as a supplementary cementitious material. Metakaolin is a high-quality pozzolanic material that is used to replace a portion of the cement in concrete, resulting in improved strength, durability, and resistance to chemical attack. The addition of steel fibers further enhances the mechanical properties of the concrete, including its flexural and tensile strength, impact resistance, and toughness. Steel fibers also improve the resistance of the concrete to cracking and spalling under cyclic loading or exposure to high temperatures.The combination of steel fibers and metakaolin in concrete can provide several benefits over traditional concrete mixes. It can improve the durability of the concrete, reduce shrinkage, increase the resistance to corrosion, and improve the sustainability of the concrete. However, the use of steel fibers in concrete requires careful attention to mixing and placement, as well as the appropriate dosage of fibers. Improper mixing or excessive fiber content can lead to balling or clumping of fibers, which can reduce the strength and durability of the concrete. In summary, steel fiber-reinforced metakaolin concrete is a promising material that can provide superior mechanical properties, durability, and sustainability compared to traditional concrete mixes. However, its successful implementation requires careful attention to mixing, placement, and fiber dosage.

Steel fiber metakaolin concrete is a type of concrete that is made by combining steel fibers, metakaolin, and cement. Metakaolin is a pozzolanic material that is added to concrete to improve its strength, durability, and workability. Steel fibers are added to the concrete to increase its tensile strength and toughness.Studies have shown that the addition of metakaolin to concrete can significantly improve its compressive strength, flexural strength, and durability. The use of steel fibers in concrete can also improve its resistance to cracking and increase its toughness. When combined, steel fiber metakaolin concrete can have even better properties than regular concrete.One study conducted by Aggarwal et al. (2019) found that the addition of 10% metakaolin and 1% steel fibers to concrete resulted in an increase in compressive strength by 22%, flexural strength by 26%, and split tensile strength by 18%. Another study conducted by Ganesan et al. (2016) found that the use of steel fibers and metakaolin in concrete resulted in better workability, reduced permeability, and improved durability.the use of steel fiber metakaolin concrete can result in a stronger, more durable, and tougher material than regular concrete. However, it is important to note that the exact properties of the concrete will depend on the specific mix design used and the properties of the materials used.

2. Concrete's mechanical properties as a result of metakaolin and steel fiber

2.1. Construction and Resources for Mechanical properties

- Workability is between 40- & 50-mm slump value
- Highest water cement ratio = 0.464
- Concrete: Regular Portland Concrete
- Coarse Aggregate: 20 mm and 10 mm
- Thin Aggregate: Sand Conforming to Grading zone IV

2.2. Combination Ratio

In order to correctly combine the concrete, metakaolin was substituted for 3%, 6%, 9%, 12%, 15%, and 18% of the cement's weight. After curing for 7, 28, and 56 days, the concrete was evaluated. Two cube and cylinder specimens were produced for each proportion, and the compressive strength and split tensile strength were computed separately with regard to their individual days. Then for each percentage of metakaolin replacement i.e., 0%, 3%, 6%, 9%, 12%, 15%, 18% steel fiber of 0.25%, 0.5%, 1% added the weight of cementfor each corresponding amount. For each proportion of steel, a cube and a cylindrical were created. Again, the fiber's shear and split tensile strengths were determined separately.

2.3 Creating Concrete Compound: Compaction

The decline should range from 40 to 50 millimeters.A vibrator and tamping tool are used to compact the complete specimen. Care is taken to eliminate gapsin the concrete. Treatment of ConcreteCuring is done to stop the loss of water, which is necessary for nourishment and subsequently for stiffening. Additionally, it protects concrete from being exposed to hot conditions and drying breezes that could cause moisture in the concrete to dry out quickly, exposing it to contraction pressures at a time when the concrete would not be able to withstand them This was done for the period of 7 days, 28 days and 56 days.

2.4 Assessment Methodology

- **Fresh Concrete Test (concrete that has just been placed):** However, it was noted that all metakaolin and fiber-reinforced mixtures reacted well to mechanical vibration and could be put and compressed without much effort. Metakaolin and fiber reinforcement provided slump test findings of about 40 to 50 millimeters.
- **Concrete testing after hardening:** Tensile power for 7 days, 28 days, and 56 days, as well as Each mix's split tensile strength was assessed in line with the TS3114 ISO 4012 standard. The average of two specimens from a blend that underwent testing was approved. As the mix's compressive strength after seven, twenty-eight, fifty-six, and divided tensile strength.The specimens were evaluated with the filling direction at a 90-degree angle to the casting direction**.**
- **Water absorption test:** Dry the blocks and cylinder at 105 degrees in an open oven for the water absorption test. until they reach 110 degrees C.The brick should weigh W1 kg if the weight is essentially consistent. Submerge the blocks and cylinder entirely for 24 hours at 27 °C. After removing the cubes and cylinders from the water and wiping the water's surface clean with a damp towel, measure the objects and set the weight to W2 kg.

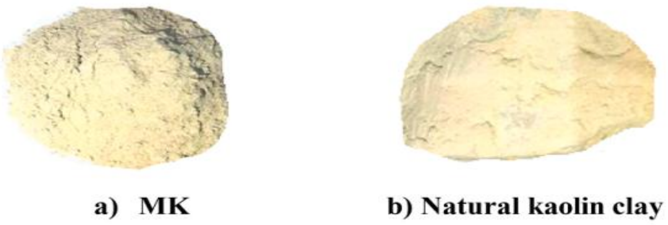
2.5 Technical Features, compression power & Tensile Strength in Splits.

The ability of cubes and cylinders to absorb water declined day by day, i.e., more for 7 days, comparatively less for 28 days, and less for 56 days. The mechanical qualities of concrete were improved when MK was used in lieu of the original substance. For concrete with a w/c ratio of 0.464, the greatest compressive strength value was 48.44 N/mm2, and the highest split tensile strength value was 11.56 N/mm2. Up to a certain percentage of metakaolin replacement, or 9%, the compressive strength and split tensile strength of the cube and cylinder were raised; however, after further replacement, the values of these properties were reduced. The addition of steel strands also increased the compressive and split tensile strengths relative to metakaolin substitution alone. The resilience will increase with more steel fiber. Maximum split tensile strength was determined to be 3.95 N/mm2 for 0.5% and 1% inclusion of steel fiber at 9% substitution of metakaolin, and the maximum compressive strength was determined to be 48.44 N/mm2 for 1% incorporation of steel fiber at 9% replacement of metakaolin. The characteristic and divided tensile strength capabilities of the concrete were significantly improved by the addition of steel fibers.

The distribution and direction of the steel fibers within the concrete may be the cause of this variation in the behavior of steel fiber reinforced concretes. In comparison to metakaolin replacement, the compressive strength of steel fiber reinforced concrete improved by 0%–3% with the inclusion of 0.25% steel fiber, 4%–11% with the incorporation of 0.5% steel fiber, and 6%–15% with the incorporation of 1% steel fiber. Similar to how adding 0.25 percent, 0.50 percent, and 1% of steel fiber to a material increased its divided tensile strength, it also increased its tensile strength by 6%, 18%, and 25% metakaolin. Strength will decline as water absorption capability increases. Instead of metakaolin, other elements can be added to concrete that alters its mechanical characteristics, such as powdered fuel ash, wonder powder, rice husk ash, coconut shell ash, glass powder, limestone fines, and ground granulated blast furnace slag.

3. Tensile strength of the high-strength concrete containing steel fiber and metakaolin

3.1 Experimental Prerequisite


a) MK

b) Natural kaolin clay

Fig. 1 – (a) Metakaolin &(b) Natural Kaolin clay (14)

Fig. 2 – Hocked end steel fibers with an aspect ratio equal to 30. (14)

As fine and coarse material, respectively, local natural sand with a fineness modulus of 2.54 and well-graded basalt with a minimum maximum size (NMS) of 10 mm were used. To comply with the ACI standard, fine and coarse gravel grading was implemented [29]. Additionally, ordinary Portland Cement (OPC) of grade 52.5 N was used. Various substitution ratios of cement were used to add metakaolin (Fig. 1), which was created by thermally processing natural kaolin clay from Aswan, Egypt, to the concrete blend. Additionally, 1 mm diameter by 30 mm long steel strands with hooked extremities was used (Fig. 2).The SF has 900 MPa tensile strength, 200 GPa elastic stiffness, and 7.94 specific gravity, correspondingly. A wide-range water reducer (Sikament R2004) was used in all mixtures to lessen the water volume and improve the mixability.

4. Tensile Strength prediction by PSO and Hybrid Regression

To forecast the outcomes of the rapid chloride penetration test (RCPT) and compressive strength test (CS) of concretes containing metakaolin, a mixed support vector regression (SVR)-particle swarm optimization (PSO) model was used. The learning factors of SVR models significantly impacts their predictive precision. As a result, PSO is used to find the best hyper-parameters for SVR to increase its generalization ability. Additionally, a sequential forward feature selection method based on SVR is suggested to reveal the most important input factors for the forecasting of CS and RCPT outcomes. The adaptive neural-fuzzy inference system (ANFIS), a well-known system modeling technique, is compared to the hybrid model's performance using 100 data examples with 25 various mix proportions that were experimentally determined.

4.1 PSO-based hybrid support vector regression

- **Enable vector machines**:

Vapnik's SVMs [30] have drawn a lot of interest thanks to their optimistic potential for simultaneous complexity reduction and forecast error minimization. It can produce an original, world-class answer. SVMs have recently been effectively used to solve many structural engineering problems. e.g., [31,32–39]. The fundamental idea behind SVRs is to map the initial data into a higher dimensional feature space and then match a linear function with the feature space's least acceptable level of complexity [40,41]. The final step is the same because it involves flattening the function as much as possible to minimize complexity and improve generalization.

Let's use the notation XY = (x, y)|(x1, y1),..., (xnd, ynd) to represent the training samples, where nd is the total amount of training examples. In linear SVR, the linear function f(x) with the form can be used to explain the relationship between the input variable xk and the forecast variable yk. e by using kernel functions to translate input vectors into a higher-dimensional feature space, which results in the non-linear SVR for the kernel function of Kh:;: i. The answer is provided by,

$$\mathrm{Ynew} = \mathrm{F(Xnew)} = \sum_{k=1}^{nd}(a_k - a_k)\,\mathrm{K}(X_k - X_{new}) + b \qquad (1)$$

Kernel functions use the weights of adjacent data points to predict the input space and map it into the feature space.
They are crucial to managing the end solution's intricacy as a result. Any random kernel function may be used, such as the radial basis function (RBF), linear kernel function, polynomial kernel function $K(X_{t}, X_{k}) = (<X_{t}, X_{k}> + 1)^{d}$, $d > 0$ etc. When compared to the other kernelsthe RBF kernel typically produces more encouraging outcomes in highly non-linear spaces [40].

- **Particle Swarm Optimization:**

Technique influenced by flocking avian behavior. Due to its effectiveness and tractability in the context of gradient free optimization algorithms, it has received recognition in the field of numerical optimization issues where the gradient is too difficult, costly to compute, or even impossible to deduce. By guiding a population of potential solutions (particles) that have been arbitrarily started around the issue's search-space, it improves the problem. Each particle has a location and a velocity, the latter of which is derived from the momentum of a moving particle. It is anticipated, but not assured, that giving the algorithm enough time (iterations) will result in a global answer that is close to optimal and has a respectable level of accuracy,

$$Vi(t+1) = w(t)\,Vi(t) + \text{ɠ}1(t)(Pbesti(t) - xi(t)) + \text{ɠ}2(t)(gbest(t) - xi(t)) \quad (2)$$

$$\text{ɠ}1(t) = c1\,r1,\ \text{ɠ}2(t) = c1\,r1(t) \quad (3)$$

$$xi(t+1) = xi(t) + vi(t+1) \qquad (4)$$

where xi(t) stands for the ith particle's location vector at time t and vi(t) for its matching velocity vector. ***Pbest***represents the prior best-known location of the ith particle, and gbest stands for the best-known position of the complete swarm or each particle's neighbors.The acceleration factors are c1 and c2, and r1 and r2 are randomly produced integers with uniform distributions that fall between [0, 1] and are made after each iteration.

4.2 Substance selection and blend

- **Materials**

According to Bogue estimates, the cement contained 54.6%, 20%, 5.1%, and 9.06% of C3S, C2S, C3A, and C4AF, correspondingly. Three different types of kaolin (MKI, MKII, and MKIII), each with a different amount of kaolinite, were thermally processed in a unique kiln for 60 minutes at 800 C to create MK. The mineralogical studies of kaolin and the chemicalmakeupp of the MK used as an additional cementitious substance correspondingly. calcareous stone with a maximum dimension of 19 mm and natural sand served as the coarse and fine aggregates for all blend patterns. In comparison to the fine aggregate, which has a specific gravity of 2560 kg/m3 and water absorption of 2.3%, the large aggregates have specific gravities of 2580 kg/m3 and 1.74%, respectively. All concrete examples were poured in potable water and allowed to cure in the same manner. To obtain the required workability, a superplasticizer (GELENIUM-110P) based on polycarboxylic acid is used.

5. Conclusion

Steel fiber reinforced metakaolin (MK) concrete (SFRM) is a type of concrete that contains steel fibers and metakaolin, which is a type of pozzolanic material that can improve the strength and durability of concrete. The addition of steel fibers can improve the tensile strength of the concrete and help to prevent cracking. SFRM can provide better performance than traditional concrete in terms of strength, durability, and resistance to cracking. The use of metakaolin can also improve the workability of the concrete and reduce the amount of water needed for mixing, SFRM can provide a viable alternative to traditional concrete for certain applications where improved strength, durability, density, and strength of the concrete and resistance to cracking are important. Using MK as a replacement substance improved the mechanical properties of concretes compared to plain ones. The concrete groups with the greatest w/b ratios of 0.35 and 0.50 had compressive strengths of 75.7 and 58.8 MPa, respectively.

The strength models created for HSFRC (high-strength steel fiber-reinforced concrete) correctly predict the compressive and splitting tensile strengths as well as the modulus of rupture at each volume fraction, according to the strength-effectiveness data.Particle swarm optimization (PSO) is a metaheuristic optimization technique that can be used to optimize the mix design of concrete. In the context of steel fiber reinforced metakaolin concrete (SFRM), PSO can be used to optimize the mix design to achieve desired properties such as strength, durability, and workability. In the context of SFRM, PSO can be used to optimize the amount and type of steel fibers and metakaolin in the mix, as well as the water-to-cement ratio, to achieve the desired properties. The PSO algorithm can be set up to minimize the cost of the mix while satisfying the performance requirements. By using PSO, engineers and researchers can design concrete mixes that are tailored to the specific application, resulting in more efficient and effective use of materials and resources. PSO can be a valuable tool in the optimization of steel fiber reinforced metakaolin concrete, helping to improve its performance and reduce its cost.

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