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Enhancing the Properties of Steel Fiber Self-Compacting NaOH-Based Geopolymer Concrete with the Addition of Metakaolin

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Abstract

There is a demand for innovative construction materials that offer enhanced mechanical characteristics while also being cost-effective and environmentally friendly. This paper examines the fresh properties and mechanical properties of geopolymerized self-compacting concrete (SCC) reinforced with steel fibers, containing 0–100% metakaolin (MK) by mass, as an eco-friendly substitute for Portland cement. SCC combinations included one or more waste cementitious materials (WCMs), such as metakaolin (MK), NaOH as an alkaline activity, and double-hook end steel fibers. For every NaOH geopolymer SCC blend, the mechanical characteristics (compressive strength, splitting tensile strength, flexural strength), as well as the new properties (lump flow, V-Funnel, L-box test), were read up. The findings indicate that combining metakaolin and steel fibers reduces the flowability of NaOH-based geopolymer SCC. On the other hand, incorporating MK and steel fibers enhances the compressive and flexural strength of NaOH-based geopolymer SCC with 25% metakaolin and 0.3% steel fiber. In contrast to the fiber-reinforced NaOH-based geopolymer SCC samples, which could transfer a sizable load even when the crack mouth opening deflection rose at flexural strength, the fiber-free SCC samples showed a brittle and abrupt fracture. The findings showed that the addition of NaOH as an alkaline activator, MK, and steel fiber had a negative impact on the fresh state properties; however, their combined use greatly enhanced the bond strength and flexural performance of the NaOH geopolymer SCC specimens.

Keywords: Self-Compacting Concrete (S.C.C.); Steel Fiber; Mechanical Properties; Metakaoline M.K; Geopolymer; Sodium Hydroxide.

1. Introduction

Because it comes in a lot of raw materials and is easy to use, concrete is the most often utilized foundation material [1]. That said, burning petroleum derivatives and the decarbonization of limestone during the production of concrete release a substantial number of ozone-depleting gases into the atmosphere (such as CO_2) [1, 2]. Also, beside aluminum, steel, standard Portland concrete (O.P.C.) is viewed as one of the most energy-escalated materials [2, 3].

Thus, the damage to the environment caused by CO_2 emissions and the high energy demands pose significant challenges to the concrete industry and the future of humankind. In lieu of traditional cement, new environmentally

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friendly foundation materials should be used to address concerns about the environment [2, 4, 5]. Geopolymer concrete had acquired consideration as a harmless to the ecosystem option in contrast to customary normal Portland concrete (O.P.C.) concrete [3]. Geopolymer cements stand out for their significant decrease in both CO2 discharges and dependence on regular assets [2]. Not at all like customary Portland concrete (O.P.C.), the development of unrefined components for geopolymer concrete doesn't include a calcining cycle, bringing about lower energy utilization [2, 5, 6]. Despite its unparalleled strength, geopolymer has significant issues with high relieving temperatures, usage, and antacid arrangement capacity. It is imperative to address these problems in order to expand the application of geopolymer concrete beyond pre-fabricated buildings [5-7]. The fluid activator arrangements should be ready no less than 24 hours prior to projecting; their profoundly destructive nature raises wellbeing concerns when utilized for in-situ applications [7, 8]. Self-compacting concrete (S.C.C.) is often utilized in structural design ventures, especially in precast enterprises, tall structures, and designs requiring thickly stuffed support [8, 9]. Self-compacting concrete's (S.C.C.) crucial characteristics include incredible flowability, the ability to fill, and the ability to pass through blocked supports without isolating or draining [8]. The idea of self-compacting geopolymer concrete is an inventive thought inside the substantial business [8, 9].

A cutting-edge substantial sort joins the properties of both geopolymer concrete, self-compacting concrete (S.C.C.) [7, 9]. Limited or nonexistent research has been conducted on self-compacting geopolymer concrete (S.C.G.C.) [8]. Further research is necessary to examine self-compacting geopolymer concrete's (S.C.G.C.) presentation in both its new (usable) and solidified states in order to better understand the anticipated applications for this material [9]. Mineral fillers, strengthening cementitious materials (S.C.Ms), assume a pivotal role in concrete by diminishing expenses, further developing usefulness, and upgrading the properties of the solidified material [10]. Fly ash and ground granulated impact heater slag (GGBFS) are commonly used as valuable cementitious materials (S.C.Ms) in concrete due to their favorable impact on the substantial's mechanical execution and their inherent financial benefits [10, 11]. Self-compacting concrete (S.C.C.) often exhibits low malleability and elasticity. Steel filaments are typically added to improve the material's appearance in order to overcome this obstacle [8, 9]. Steel filaments improve the post-breaking conduct, durability, and pliability of cement [9]. Besides, steel fiber-supported self-compacting concrete (S.C.C.) offers a better expense-to-help proportion when contrasted with customary S.C.C. [10, 11]. The improvement methods, plan methodology to meet the necessities of self-compacting concrete (S.C.C.) rely upon both the qualities of the filaments utilized, the fiber content in the blend [11]. For most designs, the optimal amount of steel strands in concrete is typically considered to be 1% of the considerable volume because to cost considerations [12, 13]. The spearheading work in the improvement of self-compacting concrete (S.C.C.) is regularly connected with what is presently known as the "Japanese Technique" [14]. According to the technique, the amount of rock in the significant mix should be about half of its pressed thickness, and the amount of sand in the mortar should be around half of its stuffed thickness (Figure 1) [14, 15]. This different evaluation of rock, sand brings about self-compacting concrete (S.C.C.) with a moderately high glue content. Therefore, numerous S.C.C. combinations accomplish a higher strength than needed [14-16]. The Japanese Technique has been implemented in the Netherlands and other European nations as a means of enhancing self-compacting concrete (S.C.C.) [14, 17].

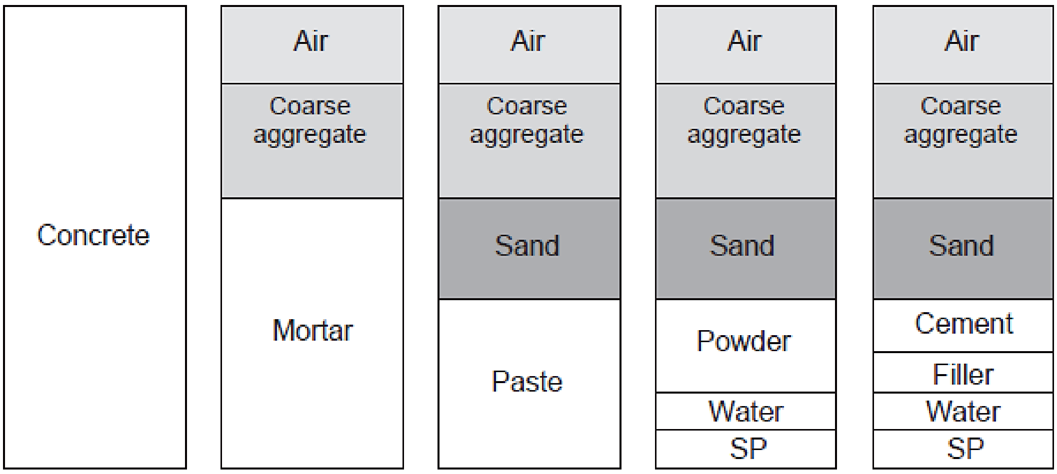

Figure 1. Schematic composition of S.C.C [1]

Soluble base actuated or geopolymer concrete is a harmless to the ecosystem material that likewise shows satisfactory execution in its solidified state. Besides, it requires less energy during creation and discharges a lower measure of carbon dioxide contrasted with standard cement [2, 18]. Geopolymer, an inorganic fastener, had arisen as an option in contrast to common Portland concrete (O.P.C.) [6, 19]. Geopolymer cement made from fly waste might be used in place of regular concrete and could also absorb dangerous radioactive materials. The mechanical and toughness execution of fly debris-based geopolymer concrete are crucial considerations in this significant sector [17, 19]. Notwithstanding fly debris, materials, for example, phosphate muck, squander glass powder, and red mud, had likewise been investigated as unrefined components for geopolymer creation [12, 17, 19]. Writing proposes that squander materials, for example, ground granulated impact heater slag, silica smoke, could be utilized as choices to fly debris in geopolymer concrete [12, 20]. The examinations demonstrate that fly debris-based geopolymer concrete is the most ordinarily utilized kind of geopolymer concrete, in spite of the fact that slag could be filled in for fly debris in G.P.C. creation. Thus, research on geopolymer cement ought to be widened [17, 20]. Self-Compacting Concrete (S.C.C.) is a liquid substantial that could move through thickly stuffed support, filling each side of the formwork, combining under its own weight [21–23]. This is explained by its high filling, its capacity to pass while maintaining excellent isolation protection, and the fact that it doesn't require external vibration. Even though the behavior of conventional geopolymer concrete (G.P.C.) has been well studied [22, 24-26], further investigation into the new, solidified properties of self-compacting geopolymer concrete (S.C.G.C.) is expected to improve this cutting-edge sort of cement [27]. Similar to regular Portland concrete, geopolymer is an inorganic polymer material with limiting qualities (O.P.C.). When triggered by a soluble arrangement, it often becomes absorbed from aluminosilicate materials like fly ash and ground granulated impact heater slag (G.G.B.S.) [11], [28]. The sub-atomic construction of the geopolymer framework is incredibly affected by its parts (source materials, activators), which could influence the geopolymerization interaction (setting, solidifying) as well as the tetrahedral organization of the geopolymer network [8, 29]. Geopolymer folio produced using fly debris or metakaolin regularly contains soluble base silicate-aluminate-hydrate (N-A-S-H) [10, 30].

Fiber-supported concrete is used for a variety of purposes, including passageways, constructions, and scaffolds. For many years, the analysis of the impact of steel strands in concrete under uniaxial stacking conditions has been a major area of focus [31, 32]. The irregular dissemination of steel strands inside a substantial lattice had been demonstrated to fundamentally work on the flexural, parting rigidity, as well as the sturdiness of cement, by overcoming any barrier between the different sides of a break's opening [33, 34]. The strength and deformity of steel fiber-built up concrete (S.F.R.C.) under biaxial stacking have been the subject of numerous experiments. [22, 35]. The discoveries of these investigations had been conflicting [34]. The vast majority of the examination had zeroed in on biaxial pressure, with just a predetermined number of studies researching the way of behaving of cement under biaxial strain [9, 25, 36]. For example, Abrishambaf et al. [35] on S.F.R.C., a series of biaxial pressure tests were performed. The review revealed that the S.F.R.C. disappointment approach was affected by strain rate and stress proportion overall. As far as strength, the discoveries of Li et al. [34] and Mohamed et al. [36]. Additionally, Gokulnath et al. [22, 37] upheld the perception that biaxial compressive strength reliably outperformed uniaxial compressive strength, as per Ramkumar et al. [38].

In comparison to its two uniaxial compressive, stiff properties, cement's ultimate strength under biaxial pressure is less. Selecting self-compacting concrete (S.C.C.) instead of regular cement (NC) may really improve the arrangement of the filaments and mitigate filament isolation, which is the separation of filaments inside the vertical, longitudinal tomahawks of the significant component. Superior presenting material S.C.C. can fill a form consistently and stream without the need for vibration [32, 37]. Figure 2 shows the upgraded direction of strands as they travel through the stream profile of self-compacting concrete (S.C.C.) [21, 31]. The stream speed profile makes the filaments reorient, adjust in a level bearing [38]. Besides, the stream pace of the substantial is more slow close to the example form, bringing about strands adjusting lined up with the shape on account of limit requirements [23, 38]. This event is known as the wall impact [36, 37].

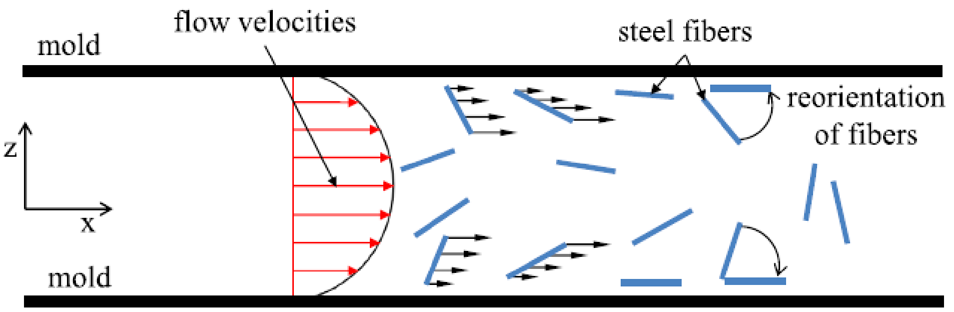

Figure 2. Reorientation of fibers due to the flow profile, wall effect [2]

1.1. The Use of Geopolymerized Metakaolin in the Restoration of Historical Buildings from the Perspective of Architects

Grout infusion for wall solidification may be the best option among the various methods available for maintaining or possibly repairing stone work structures when it's essential to preserve the initial appearance of delivered or installed brick work walls, which are frequently painted or enhanced with mosaics [39, 40]. The workmanship walls of notable structures disintegrate in light of the customary structure materials utilized (stones, blocks, lime or water-driven mortars, so on), the specific ecological burdens, and the improper materials utilized in past reclamation endeavors (concrete, polymeric materials, so on) [41, 42].

When compared to concrete-based folios, using lime had several drawbacks: lime grouts exhibited significant shrinkage levels, poor final strength, and a sluggish increase in strength. As such, pozzolanic additives are often applied to address these problems [43]. Metakaolin is a profoundly successful pozzolan that not just lifts the mechanical strength of the grout yet, in addition, upgrades its protection from the development of possibly harmful substances through the lattice [40, 41]. As per previous studies [40, 42, 44], the discoveries demonstrated that more significant levels of subbing normal pressure-driven lime (N.H.L.) with metakaolin expanded water interest to keep up with reliable smoothness in the combinations, however negligibly affected other new properties, for example, draining and volume change. Expanding the metakaolin content improved the water maintenance limit somewhat, but held water levels didn't significantly change across different replacement amounts. Likewise, Azeiteiro et al. [43] and Vavricˇuk et al. [44] exhibited that adding metakaolin while keeping up with steady ease prompts an ascent in the water interest of the new blend as the metakaolin content increments. All the while, the water maintenance limit of the grout is moved along. In its solidified express, the expansion of metakaolin supports both early-age, long-haul compressive strength of the grout. Furthermore, its bond strength could be essentially upgraded [41, 42]. L.C. Azeiteiro et al. [43] were done to foster lime-based grouts for the solidification of renders, mortars confined from their help. The objective is to create grouts that work with the materials that are already on hand, enable the coatings' attachment to be rebuilt, and strengthen the base surface. Grouts were developed and refined for use in the union of mature renders by combining metakaolin, fine sand, lime, and the ideal amount of water and admixtures [43]. One more key test in the solidified state included reproducing the solidification of separations. This started with setting up the backings (Red blocks), on which two layers of metakaoline render mortar were applied [43]. In the moderate district, a void is made, consequently loaded up with the metakaoline grout mortar under assessment (Figure. 3). Grip trial of the grouts [45] are led on these examples to survey the union of the separation between layers.

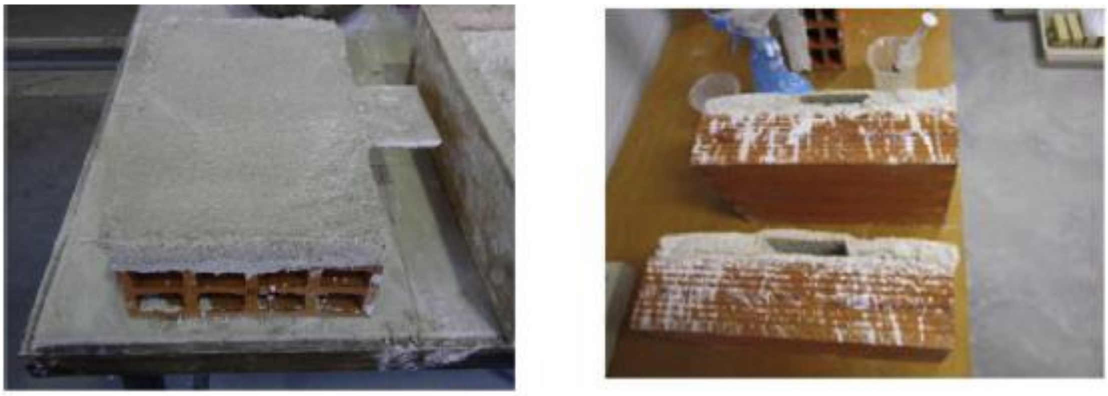

Figure 3. Specimens representing the detachment between layers, where the metakaoline grout would be injected [43]

The planning of block tests for the bond test comprised of: (I) applying a first layer of mortar onto the block; (ii) putting acrylic plates on the primary layer, afterward applying a second layer of mortar; (iii) eliminating the acrylic plates to make a separation in the delivering mortar (interlayer, squashed mortar) [40, 43]. With a fastener to total volume ratio of 1:3, the foundation mortar used to create the block tests was prepared, using air lime-metakaoline as the folio—a coarser total [41, 42].

Generally speaking, geopolymer metakaolin assumes a huge part in the rebuilding of verifiable structures because of the accompanying reasons as **a).** Similarity with Customary Materials: Geopolymer metakaolin intently matches the properties of conventional structure materials, guaranteeing consistent combination, protecting the authentic respectability of the designs, **b).** Upgraded Solidness: The utilization of metakaolin in geopolymer concrete works on the material's toughness, offering long haul strength, versatility that shields verifiable structures from natural variables, **c).** Decreased Natural Effect: Compared to conventional concrete, geopolymer metakaolin is a more environmentally friendly choice since it uses contemporary side effects like metakaolin and produces fewer byproducts from fossil fuels, ensuring more sustainable reclamation., **d).** Further developed Functionality: Geopolymer metakaolin gives fantastic usefulness, taking into account exact, productive reclamation work without compromising the nature of the fixes, **e).** Cost-Viability: The life span, diminished upkeep requirements of geopolymer metakaolin could bring about cost investment funds after some time, settling on it a commonsense decision for verifiable rebuilding ventures, f**).** Conservation of Compositional Legacy: By utilizing geopolymer metakaolin, restorers could keep up with the stylish, design legacy of authentic structures while giving them current assurance.

The introduction has been divided into several paragraphs in order to improve clarity. The importance of cement in the creation of concrete structures, the building sector overall, and its effects on the environment are all covered in the opening paragraph. The article then explores the search for substitutes for cement in order to reduce the production output of various materials. An overview of previous research on cement substitute materials and ways to initiate reactions with them that make them suitable candidates for use as geopolymer materials is given in the paragraph that follows. The conversation then centered on the function of geopolymer concrete, how it is used to create various concrete components (beams), and how it affects different concrete qualities. Architects' perspectives on the application of geopolymerized metakaolin in historic building restoration are finally presented in Section 1.1, and the introduction is concluded with a Section 1.12 outlining the importance of the research.

1.2. Research Significance

The significance of upgrading the properties of steel fiber self-compacting NaOH-based geopolymer concrete with the expansion of metakaolin had huge exploration suggestions, including right off the bat, metakaolin could upgrade the strength, sturdiness of the geopolymer concrete, giving superior mechanical properties, for example, compressive, elastic, flexural strength. Consolidating metakaolin may also improve one's ability to compact concrete, operate in a more straightforward position, and maintain stream without sacrificing overall execution. Similarly, increased metakaolin production may result in improved adhesion between the considerable grid and the steel filaments, improving fiber support and burden transfer. Additionally, exploration could assist with upgrading the blend plan of steel fiber self-compacting geopolymer concrete, including the extent of metakaolin, to accomplish the ideal equilibrium of properties.

Presently, geopolymer material provides natural benefits by employing contemporary outcomes such as fly ash and slag. The development of metakaolin could also improve manageability by providing an alternative to regular Portland concrete. Besides, improved geopolymer cement could had more extensive applications in framework undertakings, development, offering better execution in testing conditions like seismic regions, scaffolds, passages, elevated structures. This investigation may deepen our understanding of how different components work together inside geopolymer concrete, providing crucial information for future significant technological advancements. In general, adding metakaolin to steel fiber self-compacting NaOH-based geopolymer concrete offers the possibility of producing more robust, efficient, and environmentally acceptable development materials. Also, Figure 4 illustrates the research methodology.

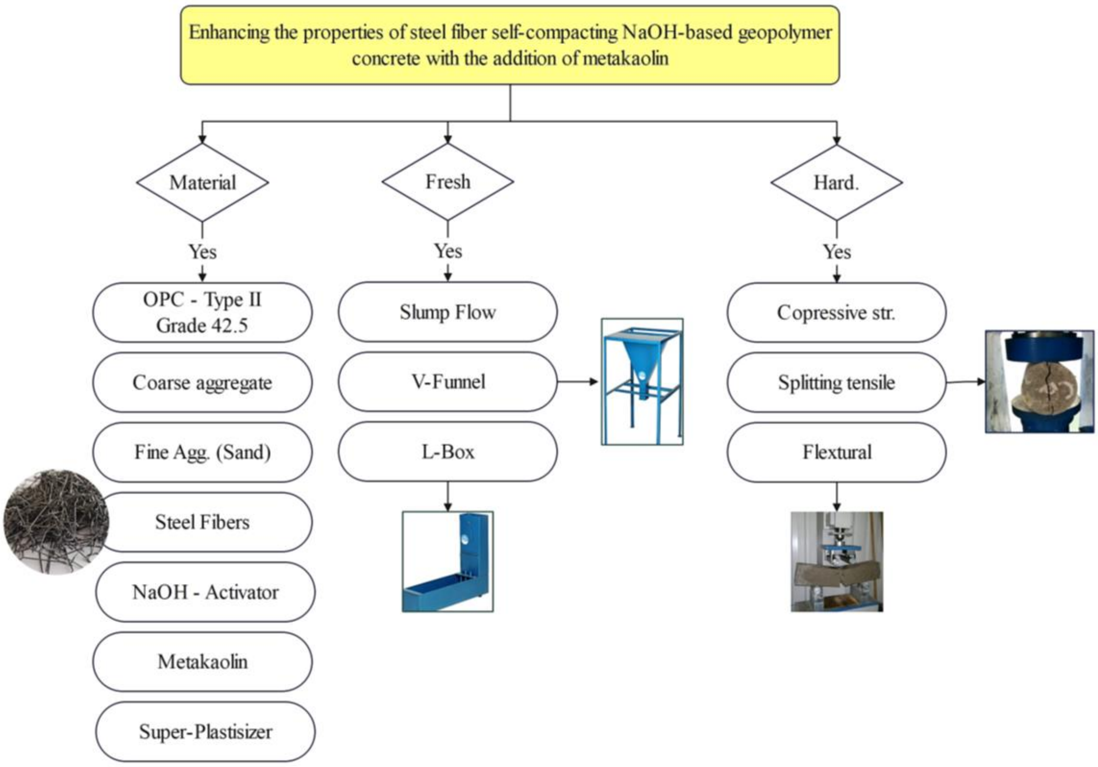

Figure 4. The research methodology

2. Material and Methods

2.1. Materials Used

A review was led utilizing 42-grade Common Portland Concrete (O.P.C) as per a particular gravity of 3.15, a typical consistency of 33%, conformed to Egyptian guidelines ES 4756/1-2013 [46], A.S.T.M C150/C150-M standard details and EN 197-1 [47]. As displayed in Figure 4-a, nearby metakaoline (M.K) filler was utilized to some degree supplant the concrete in oneself compacting fiber-built up concrete (SCFRC) for efficient reason; 92.0% of the M.K particles were more modest than 45 µm. Table 1 lists the compound components for M.K. and O.P.C. The steel filaments with the double snare ends shown in Figure 4-b were acquired from the Egyptian European Steel Fiber organization located in New Cairo, Egypt. The steel filaments' characteristics are listed in Table 2.

Figure 5. (a) Local metakaoline (M.K), (b) The 35 mm Hook End Steel Fibers

Table 1. Chemical Constituent of O.P.C, M.K

Material	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O
O.P.C	20.9	62	6.2	3.2	3.3	-	-
Metakaoline	51.47	1.15	42.78	1.48	0.18	0.5	0.26

Table 2. Typical properties of steel fiber

Fiber type	Aspect ratio	Length (mm)	Diameter (mm)	Tensile strength (MPa)	Density (kg/m^3)
Hook End Steel Fiber	47.23	35	0.75	1115	7864

Moreover, the utilization of a superplasticizer (S.P) called Sika ViscoCrete - 3425 was utilized to make concrete with high flowability, functionality while likewise dealing with its rheological properties. The S.P worked on the strength of the substantial. This S.P is a top-notch fluid item founded on the polycarboxylate admixture innovation. What's more, an air-entrained (AE) admixture was utilized to work on the steadiness of the air entrainment in the substantial blend. The substantial blends utilized normal total (NA) comprising of coarse total produced using regular squashed dolomite with an ostensible greatest size of 19 mm. The fine total utilized in all substantial blends of regular sand, which had a particular gravity of 2.58, a size dissemination going from 0.15 to 1.2 mm. The normal sand utilized followed the standard detail ASTM C33/C33M-18 [48].

Figure 6 introduces the reviewing size dissemination of the usual coarse total (NA). Moreover, the physical, mechanical properties of coarse total could be viewed as in Table 3. Sikament-163M adjusted to ASTM C494/C494M-17 [49] was utilized with one degree of 2.5% by weight of cementitious material. The consumable water conforms to ASTM C1602/C1602M-22 [50] was utilized in blending the dry materials, restoring the substantial examples. The water to solidify proportion (W/C) was steady for all blends, equivalent to 0.27.

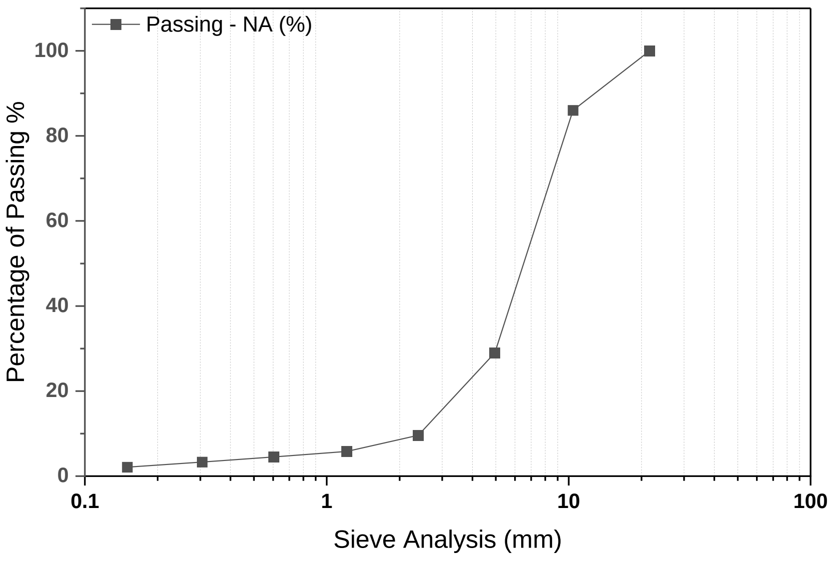

Figure 6. Particle size distribution for Natural aggregate (NA)

Table 3. Mechanical, Physical Properties of Natural aggregate (NA)

Property	Natural Aggregate	
	Crushed dolomite	Sand
Specific gravity	2.65	2.58
Volume density	1430	1612
Water absorption%	0.86	1.9
Los Angeles abrasion %	17.56	-
Crushing value %	17.93	-

A basic activator made out of NaOH arrangements was used. The essential variable examined in this examination incorporated the molarity of the NaOH arrangement. One single focus was employed. The review examined fixations of NaOH at a molarity of 8 (M). When the NaOH arrangements were finished, they were allowed to stand in for 24 hours before being combined with other combination components.

The combination of sodium hydroxide arrangements was permitted to represent one day prior to being utilized in the geopolymerization cycle. NaOH was in piece shape with a virtue of 96%, a thickness of 2.13 g/cm^3, a temperature at which a substance melts of 318 °C, and a sub-atomic weight (M.W.) of 40 g/mol. For example, a 50 kg bundle of sodium silicate basic could be gained from the Morgan Speciality Synthetic Compounds Organization situated in Al Obour city, Egypt.

2.2. Mix Proportion

The mixing framework was performed by the Egyptian principle's ES 4756/1-2013 [46], BS 1881-124:2015 standard details [51]. The blends were replaced with M.K. in paces of 25%, half, 75%, and 100 percent (by weight) of the planned content of concrete. The Twofold Snare end steel strand content was 6.9 kg/m^3 for all fiberd mixes as introduced in Table 4. The NaOH molarity is 8 mole for all antacid-actuated blends. The blend's representation Na0-PC100-MK0-F0, for example, suggests that NaOH is not included in this blend, that the O.P.C. content is 100% from the planned concrete substance, that the M.K. content is 0% from the concrete weight, and that the steel fiber content is 0%.

Table 4. Mix proportions

Mix designation	Mix description	Water	Cement	Metakaoline	Natural Agg.	Sand	Fiber
		Lit.	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3
C1	Na0-PC100-MK0-F0	223	505	0	815	720	0
C2	Na8-PC100-MK0-F0.3	223	505	0	815	720	6.9
M25	Na8-PC75-MK25-F0	223	379	126	815	720	0
M25/F0.3	Na8-PC75-MK25-F0.3	223	379	126	815	720	6.9
M50	Na8-PC50-MK50-F0	223	252.5	252.5	815	720	0
M50/F0.3	Na8-PC50-MK50-F0.3	223	252.5	252.5	815	720	6.9
M75	Na8-PC25-MK75-F0	223	126	379	815	720	0
M75/F0.3	Na8-PC25-MK75-F0.3	223	126	379	815	720	6.9
M100	Na8-PC0-MK100-F0	223	0	505	815	720	0
M100/F0.3	Na8-PC0-MK100-F0.3	223	0	505	815	720	6.9

For the purpose of the mixing process, Fibers, Metakoline, Cement, coarse and fine aggregates were blended for 2.5 minutes. After one minute, the mixture was combined for a further two minutes with the addition of the NaOH as alkali activator, superplasticizer, and more water. In order to guarantee homogeneity and uniformity, fresh concrete was then further mixed for three minutes.

2.3. Preparation, Curing of Specimens

For each blend, six (150 × 150 × 150 mm) solid shapes were prepared to choose the significant's compressive strength at 7, 28 days (see Figure 6). Moreover, three substantial chambers with a level of 300 mm, a measurement of 150 mm were projected for every blend to complete the parting rigidity tests (see Figure 6). Three standard substantial crystals with square cross-segments of 100 mm by 100 mm, lengths of 400 mm were made to evaluate the flexural strength of the substantial (Figure 7).

Figure 7. Prepared concrete cubes, cylinders, prisms

A mechanical blender was used to get a homogeneous, significant mix. The mixing technique for each S.C.C blend involved three phases. In any case, the concrete, regular total, sand, steel fiber, and metakaoline (O.P.C., NA, FA, Fiber, M.K.) were mixed in the significant blender for around 2 min. Second, around 80% of the mixing water was added to the significant blender, mixed for another 2 min. Finally, the superplasticizer, the extra 10% of the mixing water were added, mixed until a homogeneous S.C.C. mix was gotten. All mixing processes were aimed at a temperature extent of 20–25 °C with a general clamminess of 95%, according to ES 4756/1-2013 [46]. After the mixing strategy was finished, new significant tests were finished. Resulting to anticipating, the coordinated models were left for 24 h in their molds. The strong shapes, chambers, and precious stones were then stripped away, brought down in clean, customary water for easing until the testing day. Their sides were stripped away, a short time later covered with wet material for emanates.

2.4. Test Procedures

The program of exploration was divided into three phases. The primary focus was on the novel characteristics of the S.C.C blends. Examining the hardened S.C.C. mixes' mechanical characteristics (such as their compressive strength, parting rigidity, and flexural strength) was part of the subsequent step. Using E.C.P. 203, the novel characteristics of the S.C.C. blends, such as the droop stream, V-channel, and L-confine, were evaluated [46]. The downturn stream (see Figure 8-a) breadth ought to be somewhere in the range of 550–850 mm. The L-box (see Figure 8-c) test estimated the isolation of S.C.C., with a hindering proportion (H2/H1) necessity of more than 80%. The V-pipe test (see Figure 8-b) surveyed the filling limit of S.C.C. with a most extreme grain size of 20 mm. The appropriate release time for this test went from 6 to 12 seconds.

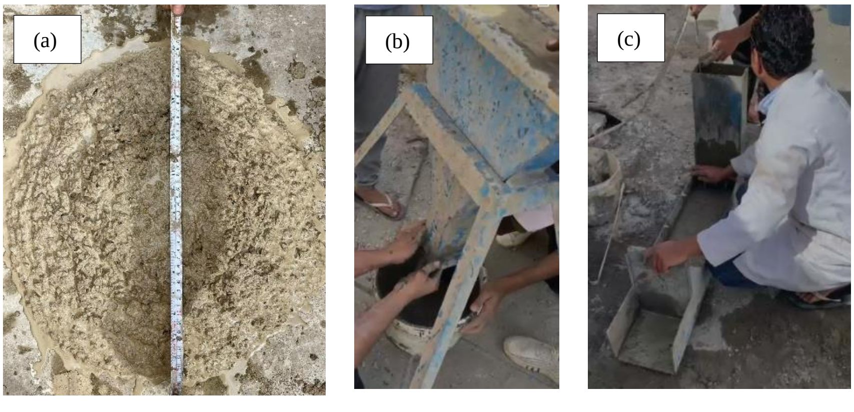

Figure 8. S.C.C Fresh properties tests

The compressive strength trial of all examples was directed utilizing a widespread water-driven testing machine with a limit of 2000 KN, as shown in Figure 9-a. The tests were completed as per the rules framed in BS 1881-116 to guarantee normalized, exact evaluation of the examples [51], ASTM C642-97 [52] at ages 7, 28 days. Parting elasticity (FSPT) was led utilizing a chamber of (300×150) mm in agreement with ASTM C496-96 [53] (see Figure 9-b). For every combination, three examples were exposed to testing. To stack the instances, compressive force was applied along the length of the chambers. Remaining unclear due to the isolation of the greatest burden (2P) backed by instances using the appropriate mathematical variables (πDL). The recorded outcome addresses the typical worth got from the three-fold examples. The flexural strength tests (see Figure 9-c), as well as the four-point stacking flexural tests, were directed by ASTM C78 [54].

Figure 9. Test setup for the hardened concrete. (a) Compressive strength, (b) Splitting tensile strength, (c) Flexural strength

3. Results, Discussion

The new significant properties for the S.C.C mix in with different blends of M.K, steel filaments to the extent that rut stream, L-box, V-channel test results are kept in Table 5.

Table 5. Fresh S.C.C mixes characteristics

Mix designation	Mix description	Slump Flow (mm)	V-Funnel (Sec.)	L-Box (H_2/H_1)
C1	Na0-PC100-MK0-F0	795	6.5	0.92
C2	Na8-PC100-MK0-F0.3	760	6.5	0.92
M25	Na8-PC75-MK25-F0	750	7	0.89
M25/F0.3	Na8-PC75-MK25-F0.3	735	8	0.87
M50	Na8-PC50-MK50-F0	730	8.5	0.86
M50/F0.3	Na8-PC50-MK50-F0.3	710	8.5	0.85
M75	Na8-PC25-MK75-F0	705	10	0.85
M75/F0.3	Na8-PC25-MK75-F0.3	683	10.5	0.84
M100	Na8-PC0-MK100-F0	675	11	0.82
M100/F0.3	Na8-PC0-MK100-F0.3	656	11	0.80

3.1. Slump Flow Results

Each worth in this Table 5 addresses the normal of two opposite estimations of downturn stream distances across. As displayed in Table 5, the rut stream values for the S.C.C blends went from 656 to 795 mm which meeting with Patel & Shah [9] and Xu et al. [55]. The downturn stream for blends containing 0.3% steel fiber (M25/F0.3 - M50/F0.3 - M75/F0.3 - M100/F0.3) diminished by 2%, 2.74%, 3.12%, 2.81% separately, in contrast with same blends without filaments (M25 - M50 - M75 - M100). Similar perceptions were gotten for blends C1, C2, as displayed in Figure 10. Moreover, expanding the NaOH to blends impacted the interlocking way of behaving, expanded thickness, the grating, surface region, which diminished flowability, which consents to [9, 10, 55].

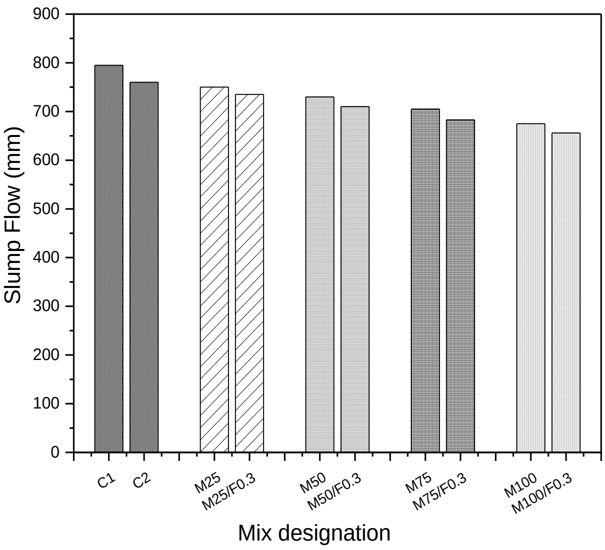

Figure 10. Impact of NaOH, Steel Fibers Content on Slump Flow Results

3.2. V-Funnel, L-Box Results

The V-Pipe test results are kept in Table 5, Figure 11. The V-Pipe stream time ran between 6 s to 11 s, which followed, understanding with ECP-203-2020 [46]. It is seen that the V-Pipe of the S.C.C mixes expanded with expanding the Substance of M.K%. This lead could be fundamentally attributed to the jauntiness, surface brutality, surface porosity of metakaoline, which acclimatized more water, expanding the crushing between the aggregate, substantial paste. The V-Pipe stream times of mixes M.K without, with steel filaments (M25/F0.3 - M50/F0.3 - M75/F0.3 - M100/F0.3) increments by 23.7%, 30.76%, 61.53%, 69.23% independently, as indicated by C2 blend. Similar perceptions were acquired for blends C1, C2, as displayed in Figure 10. The L-box test values for the S.C.C mixes are shown in Figure 11, are summarized in Table 5. The H2/H1 extent, implied as the hindering extent, evaluates the movement of concrete, the disconnection impediment of the S.C.C prompted by the steel filaments. It was seen that the H2/H1 regard lessened as the M.K extent somewhat diminishing. The basic clarification, comparably similarly as with the trench stream case, was that while expanding the M.K% replacement level, concrete turned out to be more limit as a result of the irregularity, brutality of the M.K, which then, extended the capacity to obstruct, crushing of the S.C.C blends. The effect of P.V.A fibers on the L-box results of the S.C.C mixes in with 100% M.K content is shown in Figure 12.

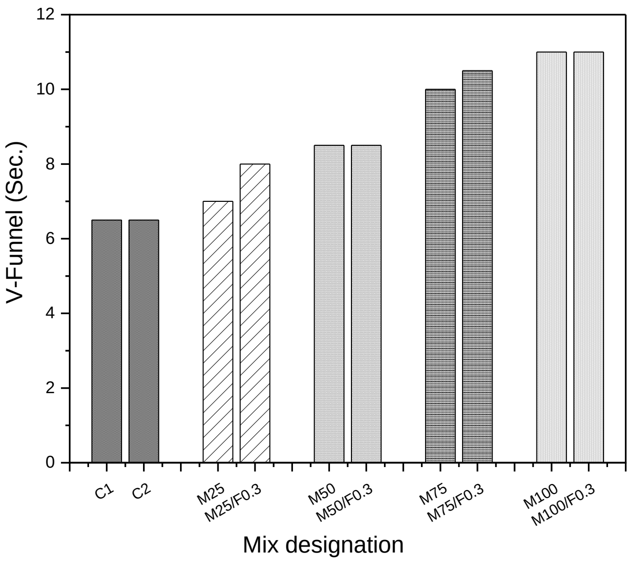

Figure 11. Impact of NaOH, Steel Fibers Content on V-Funnel Results

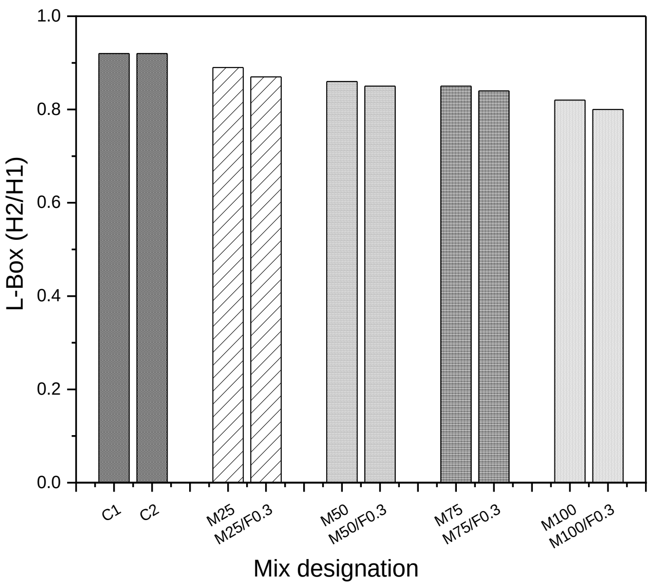

Figure 12. Impact of NaOH, Steel Fibers Content on Slump Flow Results

3.3. Compressive Strength, Splitting Tensile Strength

Table 6 gave the Mechanical properties of Geopolymer S.C.C M.K-Steel fiber, Additionally, Figure 12 blueprints the effect of the NaOH, M.K, steel fiber content on the 28-day shape compressive strength of the S.C.C blends. The compressive strength of the mixes with (M25/F0.3 - M50/F0.3 - M75/F0.3 - M100/F0.3) expanded by 1.60%, 2.01%, 3.27%, 5.02% in the cases of 25%, half, 75%, 100 percent M.K, independently, contrasting, the (M25 - M50 - M75 - M100) mix. Parting elasticity showed same bahavior. Additionally, similar perceptions were acquired for blends C1, C2, as displayed in Figure 13. Figure 14 showed the connection between compressive strength, parting elasticity at 28 days.

Table 6. Mechanical properties of Geopolymer S.C.C with M.K-Steel fiber

Mix designation	Compressive Strength		Splitting Strength (MPa)	Flexural Strength (MPa)
	7-days (MPa)	28-days (MPa)		
C1	38.36	43.60	4.30	4.80
C2	34.50	42.25	4.10	4.40
M25	31.45	39.80	3.55	4.00
M25/F0.3	31.66	40.45	3.00	4.30
M50	30.20	38.90	3.50	4.85
M50/F0.3	30.75	39.70	2.90	3.90
M75	28.65	35.40	3.40	4.30
M75/F0.3	27.40	36.60	2.85	3.70
M100	26.85	32.10	2.80	3.60
M100/F0.3	26.75	33.80	2.70	3.80

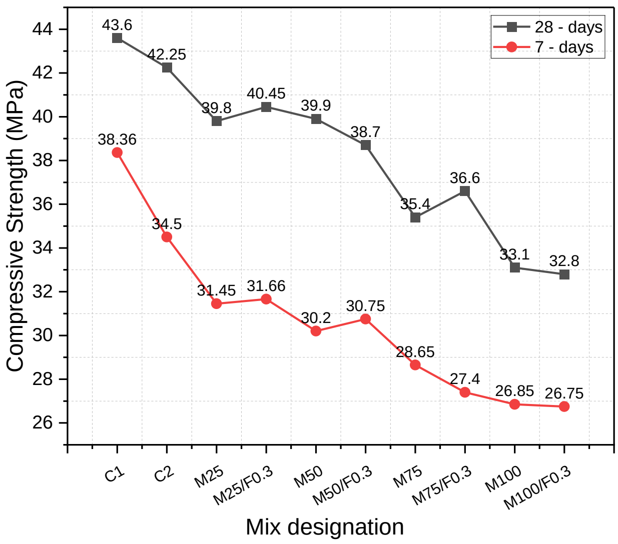

Figure 13. Compressive strength at 7, 28 days of hardened M.K-Steel fiber concrete

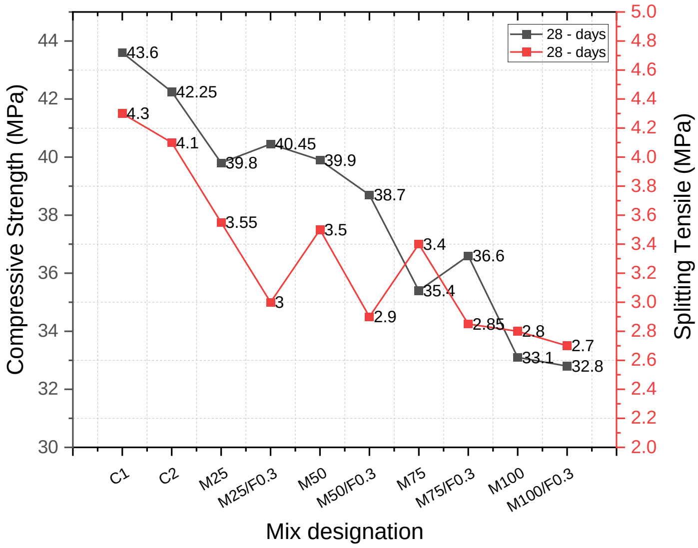

Figure 14. Compressive strength at 28 days Vs Splitting tensile strength

According to Figures 15-a and 15-b, in self-compacting NaOH geopolymer concrete containing metakaoline and steel fibers, the form of compression test failure can exhibit unique characteristics due to the combined effects of the polymer matrix, the self-compacting nature of the mix, and the reinforcing steel fibers. Here's an explanation of the typical forms of compression test failure in such concrete. In conventional concrete, compressive failure is typically brittle, characterized by a sudden and catastrophic fracture. This is due to the low tensile strength and limited ductility of the cement matrix.

Figure 15. Crack and failure pattern of (a) Compressive strength test, (b) Splitting tensile strength test and (c) Flexure strength test

Initial cracks in SCPC containing steel fibers typically start at points of stress concentration, such as aggregate-matrix interfaces or locations with micro-defects. The cracking pattern may be more distributed and less severe in fiber-reinforced compared to traditional concrete. Cracks tend to be finer and more numerous due to the bridging action of the fibers and metakaoline fines. The failure mode of self-compacting geopolymer concrete containing steel fibers under compression is a complex interplay between the polymer matrix, the self-compacting nature of the mix, and the reinforcing action of the steel fibers. The overall behavior tends to be more ductile and tough compared to conventional concrete, with features such as fiber pull-out, crack bridging, and progressive damage contributing to improved post-peak performance and residual strength.

3.4. Flexural Strength

The effect of the S.C.C extent on the 28-day flexural strength is kept in Table 6, Figure 16. The 28-day flexural strength for the mix (M25/F0.3 - M100/F0.3) expanded by 7.5%, 5.55% for the examples of 25%, 100% M.K, independently, appeared differently in relation to the (M25 - M100) mix. The two social events (M50/F0.3 - M75/F0.3) showed comparable abatements, indicating that flexural strength declined as the S.C.C. prolonged. The effect of the steel fiber, S.C.C blend type on the 28-day flexural strength is addressed in Figure 16.

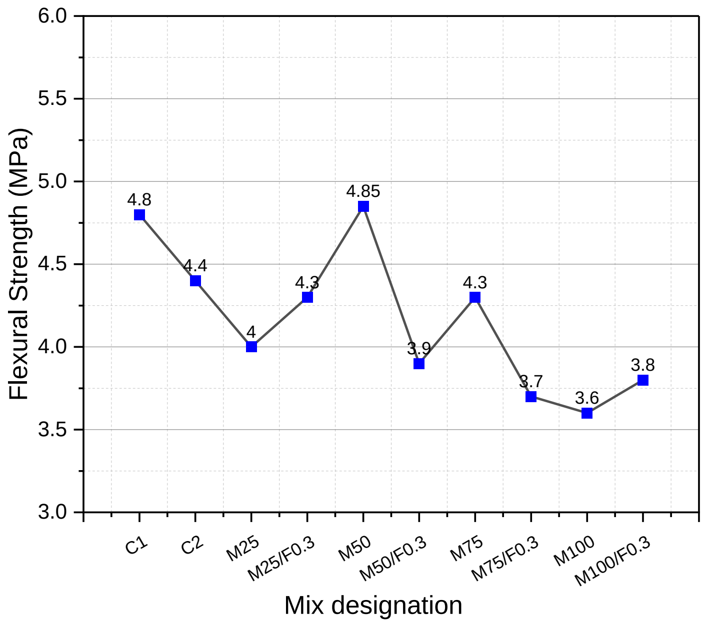

Figure 16. Flexural strength at 28 days of hardened M.K-Steel Fiber

According to Figure 15-c, the inclusion of steel fibers significantly alters the failure mechanism compared to conventional concrete. Here's a detailed explanation of the typical form of flexural failure in such concrete: Under flexural loading, initial cracks usually form at the tension side of the beam, where tensile stresses are highest. In mixes with steel fibers, these initial cracks may be finer and more distributed compared to conventional concrete. As cracks develop, the steel fibers span the cracks, providing bridging action that helps to transfer loads across the cracks. This mechanism increases the load-carrying capacity and toughness of the concrete. The flexural failure of self-compacting geopolymer concrete containing steel fibers is characterized by enhanced toughness, ductility, and energy absorption compared to conventional concrete. The presence of steel fibers leads to a distributed cracking pattern, fiber bridging, and pull-out mechanisms, which significantly improve the post-peak performance and residual strength of the concrete. This makes SCPC with steel fibers a durable and resilient material suitable for various structural applications where flexural performance is critical.

4. In Contrast to Previous Studies

Geopolymer concrete has been the subject of several prior studies and research projects that looked into its potential as a partial or total cement substitute. Table 7 provides an extensive comparison between the outcomes and findings reported in the current study and the conclusions and presentations from these previous research attempts. Gülsan et al. [5] demonstrated that the addition of steel fiber and nano-silica had a negative impact on the specimens' fresh state attributes; nevertheless, their combined use greatly increased the SCGC specimens' bond strength and flexural performance. Furthermore, it was discovered that steel fiber had a stronger influence on bonding strength and flexural performance than nano-silica did on fresh state characteristics and compressive strength. Patel & shah [9] At room temperature and at 70 °C, the ideal percentage replacement of RHA with GGBFS is 5% and 15%, respectively. When the temperature is cured at 70 °C instead of room temperature, a greater strength is achieved. 15% of RHA at 70°C and 5% of RHA at room temperature, according to SEM imaging, have a denser microstructure and are hence stronger.

Table 7. A summary of the key findings from earlier research using self-compacting geopolymer concrete

Authors	Location / Geopolymer type	Fiber type	Geopolymer Materials	Used Activator	Compressive Strength	Flexural Strength	Splitting Tensile Strength
Current study	Egypt / Self Comp. Concrete	Steel Fiber	Metakaoline	NaOH	Dec. with av. Value (3-9) %	Dec. with av. Value (4-8) %	Dec. with av. Value (4-8) %
Sayed et al. (2023) [56]	Egypt / Recycled Concrete	Nil	Silica Fume	NaOH	Increasing with ac. Value (4-11) %	Inc. with av. Value 12%	Increasing with ac. Value (7-12) %
Ahmed et al. (2023) [15]	Egypt / Self Comp. Concrete	Nil	Fly Ash Metakaoline	Nil	Dec. withav. Value (3-9) %	Dec. with av. Value 5.4%	Dec. with av. Value 4%
Patel & Shah [10]	India / Self Comp. Concrete	Nil	GGBFS, RHA	NaOH, Na_2SiO_3 CaOH	Increasing with ac. Value 8%	Inc. with av. Value 3%	Increasing with ac. Value 6.5%
Awoyera et al. (2020) [28]	Vietnam , Turkey / Concrete	Nil	GGBFS and Fly Ash Class F	NaOH, Na_2SiO_3	Dec. with av. Value 4%	Dec. with av. Value 5%	Dec. with av. Value 7%

Also, Ahmed et al. [6] mentioned that, for all SCC mixes, the flexural behavior of SCC beams (load-carrying capacity, crack pattern, midspan deflection, and flexural stiffness) as well as the fresh properties (slump flow, V-funnel, and L-box test) and hardened properties (compressive strength, splitting tensile strength, and flexural strength) were examined. It is possible to generate SCC with a 100% replacement of RCA with little effects on the properties of the concrete, as demonstrated by the results of fresh and hardened concrete. The best mixture that met the EFNARC requirements and had good fresh qualities was a mixture of SCC with 100% RCA replacement, 20% MK, and 22% FA. Comparing the 100% RCA replacement to the control mixture, the compressive strength decreased by 8.20%, but the ultimate load and flexural stiffness increased by 3.20 and 16.25%, respectively. Al Sayed [56] stated that, the use of sodium hydroxide in concrete has several important benefits, including accelerated hydration and strength development, improved workability, increased pH for corrosion protection, activation of supplementary cementitious materials, control of alkali-silica reaction, and enhanced chemical resistance. However, its use must be carefully controlled, as excessive amounts can lead to undesirable effects such as increased risk of alkali-aggregate reactions or potential health hazards during handling. Properly dosed, sodium hydroxide can significantly improve the performance and durability of concrete in various applications.

5. Conclusions

This paper analyzed the replacement of concrete (O.P.C.) with metakaoline significant sums (M.K.) with different extents (0%, half, 75%, 100 percent) in making self-compacting concrete (S.C.C.). Different pieces of reinforcing cementitious materials (S.C.C., for instance, metakaoline (M.K.), as well as steel fiber fibers, were coordinated into the S.C.C. mixes. The new properties (droop, V-Channel, L-box test), hardened properties (compressive strength, parting rigidity, flexural strength). As shown by the exploratory program coordinated, the results separated, and the going with finishes could be drawn:

- At 100% M.K., mixes in with steel fiber fibers had less new properties than those without steel fiber strands, showing the opposing effect of steel fiber fibers on the new properties.
- Adding steel fiber fibers to the geopolymerized NaOH S.C.C. mixes redesigned the splitting versatility; in any case, it lessened compressive, flexural strength at a replacement level of 100% for M.K.
- The compressive strength decreased for the ternary geopolymerized NaOH S.C.C. mixes, including adding M.K. to cement. Regardless, ternary mixes with M.K., steel fiber achieved asymptotic strength stood out from the reference mix, showing that the mixes, including a blend of M.K., steel fiber work on the mechanical properties of geopolymerized NaOH S.C.C. mixes.
- S.C.C. combinations with metakaolin, steel strands need more superplasticizer than S.C.C. without filaments, metakaolin to keep up with reasonable self-compacting properties. As the metakaolin content builds, the flowability of S.C.C. blends marginally diminishes, while thickness, strong strength rise.
- The test results highlight the meaning of S.C.C.'s rheological properties, like adequate usefulness, for improved mechanical execution, strength. Thusly, it is fitting to look at the consolidated effect of metakaolin, mixture steel, engineered strands at various volume portions.
- For superior mechanical properties, the appropriation, direction of steel filaments is urgent in geopolymerized NaOH S.C.C. In a few geopolymerized NaOH S.C.C. blends, it became obvious that some steel filaments didn't scatter as expected, prompting a lopsided circulation of the strands.
- Such elite execution S.C.C. shows extraordinary potential for use in development applications where higher break opposition, protection from chloride entrance is required.

6. Declarations

6.1. Author Contributions

Conceptualization, S.E., H.M.A., and H.A.E.; methodology, H.A.E., S.E., and S.M.M.S.; formal analysis, H.M.A. and A.A.E.; data curation, H.A.E., S.E., and H.A.E.; writing—original draft preparation, H.M.A. and S.E.; writing—review and editing, S.E. and H.A.E.; supervision, H.A.E. and S.M.M.S. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.3. Funding and Acknowledgements

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6.4. Conflicts of Interest

The authors declare no conflict of interest.

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