https://doi.org/10.3311/PPci.22519

Periodica Polytechnica Civil Engineering, 68(2), pp. 392–402, 2024

Experimental Study on Direct Shear Strength of Fiber Reinforced Self Compacting Concrete under Acid and Sulfate Attack

Ahmad Haydar Awrahman[1], Necip Altay Eren[2*], Abdulkadir Çevik[1], Azad Abdulkadir Mohammed[3]

[1] Department of Civil Engineering, Faculty of Engineering, Gaziantep University, 27310 Gaziantep, Turkey
[2] Department of Construction, Technical Science Vocational Schools, Gaziantep University, 27310 Gaziantep, Turkey
[3] Civil Engineering Department, College of Engineering, University of Sulaimani, Zone 501 Sulaimani, Kurdistan Region, Iraq
[*] Corresponding author, e-mail: altayeren@gantep.edu.tr

Received: 02 May 2023, Accepted: 06 October 2023, Published online: 06 November 2023

Abstract

This study primary is to investigate the shear strength of self-compacting concrete (SCC) reinforced by steel-fiber (SF) and polypropylene-fiber (PPF) in different environmental conditions: the air, sulfate ($MgSO_4$ with a concentration of 5%) and acid (H_2SO_4 with a concentration of 5%). The study also examines the effect of fiber volume fraction on the workability, shear strength, compressive strength, and splitting tensile strength of fiber reinforced SCC. The article aims to determine the durability effects of both fibers and their resistance to aggressive environmental conditions. The contribution of this article is an experimental investigation on the shear strength of SCC reinforced by SF as well as PPF in 3 different environmental conditions after 30 days of exposure. The study also investigated the fresh and mechanical properties of 5 different mixtures of SCC with/out 0.1% and 0.2% fibers. The study also concluded that PPF decreased the workability of SCC badly, and special care must be taken when selecting its volume fraction. Also, it was found that generally shear strength of SCC mixes enhanced with increasing SF and PPF volume fraction. Moreover, it was found that both fibers have good durability effects, and resist aggressive environmental conditions, with the best results obtained from samples containing 0.2% SF. In the air condition, while the compressive strength, shear strength and tensile strength results were 52.6MPa, 6.43MPa and 3.91MPa, in the sulfate condition those were 46.37MPa, 6.55MPa and 3.59MPa, and in the acid condition those were 34.4MPa, 5.5MPa and 3.46MPa, respectively.

Keywords

fiber reinforced self-compacting concrete, polypropylene fiber, steel fiber, direct shear strength, workability

1 Introduction

The force applied parallel to the cross section of a structural member is called the shear force, and the effect of the applied shear force on the unit area is called shear stress. Shear force is a force that is frequently encountered and considered when designing structures in civil engineering. Such situations include precast reinforced concrete joints, corbels, brackets, elements with shear span smaller than the effective depth where shear and direct shear is much more likely to occur, as well as column foundation connections that are subject to significant shear forces. This strength can be of great importance in many types of reinforced concrete structures [1–3]. In some cases, due to the presence of tension caused by thermal deformation or restraint shrinkage, fracture has occurred in the shear plane before the shear force is applied [4].

Recent studies on the durability of RC have focused largely on chemical attacks because of the rapid population growth and hazardous waste in urban area. The issue of conventional concrete degrading in the presence of chemical attacks is one that investigators are aware of, and ongoing investigations seek to prevent this from happening. Particularly in seismic zones, structures are susceptible to chemical attacks, axial force, shear stresses, and bending moments. Due to the loss of mechanical strength caused by chemical attack, structures in such an environment are vulnerable to seismic loads, and failure of the structures is unavoidable and inevitable [5].

SCC is a novel, high-performance concrete that fills restricted areas and spreads easily into the area under its weight [6]. SCC can increase efficiency in structural appli-

Cite this article as: Awrahman A. H., Eren, N. A., Çevik A., Mohammed A. A. "Experimental Study on Direct Shear Strength of Fiber Reinforced Self Compacting Concrete under Acid and Sulfate Attack", Periodica Polytechnica Civil Engineering, 68(2), pp. 392–402, 2024. https://doi.org/10.3311/PPci.22519

cations like repair and make it easier to fill in constrained portions. This type of concrete is widely used to facilitate construction operations, especially in sections with special challenges for casting and vibration, such as the underside of beams [7]. The SCC has improved compressive strength, stiffness, low electrical and thermal conductivity, low combustibility, and low toxicity. But samples with crumb rubber particles in self-compacting concrete was showed a decrease in some mechanical properties [8]. However, its use is limited due to its brittle and weak structure under tensile stress [6]. However, the developments in FR composites (FRC) have provided a technical basis for overcoming these flaws [9]. A concrete mix that normally consists of cement, water, fine and coarse aggregate, and fibers also comprises tiny particles of reinforcing material known as fibers. Some of the most well-known fibers include steel, glass, asbestos, carbon, and polypropylene. Cracks may spread slowly or rapidly as a result of the force applied to the concrete. Using fiber in concrete is one of the methods used to reduce or stop the propagation of cracks. The fibers help carry the load and boost the material's tensile strength if their elastic modulus is higher than the elastic modulus of the concrete or mortar binder [6]. The addition of fiber to SCC increases the durability and mechanical performance of concrete compared to conventional concrete [10]. In addition, the addition of fiber improves concrete's tensile strength and toughness. Also, it reduces the shrinkage and creep stress of concrete [11].

Lack of theoretical knowledge or poor understanding of engineering science problems can lead to incomplete designs and potentially high repair costs. One of the situations that should be considered while designing the structure is the situation related to how the mechanical properties of concrete exposed to acid and sulfate attack will change. Therefore, accurate knowledge of the acid and sulfate damage processes of cementation materials is essential for direct shear tests. In the aim of the study, the effects of acid and sulfate were investigated on the direct shear strength, split tensile strength and compressive strength of fibrous RC samples.

When the studies in the literature are examined, there are studies on various mechanical properties of SCC reinforced with fibers. However, studies on the mechanical properties of SCC reinforced with SF and PFF fibers exposed to sulfate or acid are limited. Moreover, the study presents an experimental investigation on the shear strength of SCC reinforced by SF as well as PPF in 3 different environmental conditions: air, acid and sulfate. The study also investigates the fresh properties and other mechanical properties of FRSCC specimens. The article contributes to the literature by showing that both SF and PPF have good durability effects and resist aggressive environmental conditions, with the best results obtained from samples containing 0.2% SF. It was also found that PPF decreased the workability of SCC badly, and special care must be taken when selecting its volume fraction. However, SF slightly affects workability and does not decrease it compared with PPF.

2 Material and method

Self-Compacting Concrete's material composition is extremely crucial and delicate since any changes might have a negative impact on the material's capacity to flow, pass, or separate. Therefore, its composition was chosen very carefully. In addition, after each trial mix was designed, the compliance of the Self Compacting Concrete with the sensitivity of EFNARC, (2005) [12] and ACI Committee 237, (2007) [13] was checked. Due to there was a large volume of powder in SCC, Fly ash was used with Cement. In addition, PPF fiber was used in different fraction.

2.1 Binder

In this study, Type I Normal Portland cement (Delta Cement) produced by Bestun Group in Sulaymaniyah, Iraq was used. The quality of the cement complies with the Iraq (I.O.S 5/2019) standard [14]. The chemical composition and physical properties of the cement used were given in Table 1 and Table 2, respectively.

Table 1 Chemical composition of cement

Component	Result Obtained (%)
CaO	61.82
SiO_2	19.38
Al_2O_3	4.89
Fe_2O_3	3.11
MgO	4.15
SO_3	2.25
LOI	3.46
In.R	0.21
LSF	0.97
C3S	60.62
C2S	10.66
C3A	7.69
C4AF	9.46
Alkali ($0.658 \times K_2O + Na_2O$)	0.6

Table 2 Physical properties of cement

Description	Unit	Result	O.P.C/acc to I.O.S 5/2019
Initial setting time (Vicat)	Minute	138	≥ 45 dk
Final setting time (Vicat)	Hour	2:38	≤ 10 Hours
Fineness (Blaine)	cm^2/gm	3338	Min. 2800 cm^2/gm
Soundness (Le-Chatlier)	mm	1	Min. ≤ 10mm
02 Days strength	MPa	24	Min. 20MPa
28 Days strength	MPa	44	Min. 42.5MPa

2.2 Aggregate

The fine aggregate used in this study is the natural river sand obtained from the Kaneby quarry, which was given as a result of the sieve analysis in Fig. 1(a). The sieve analysis results obtained from the Tanjaro quarry as coarse aggregate was given in Fig. 1(b) [15].

2.3 Fly ash

In this study, fly ash was used and Class F fly ash whose chemical properties given in Table 3 were used. The specific gravity of this fly ash is 2.02 gr/cm^3. The cement and supplementary cementations materials' Blaine fineness, which measures the particle size or fineness of the materials, was 5230 kg/m^3. The cement paste in SCC is crucial since it serves as an aggregate carrier. Therefore, using the FA, extra cement paste has been added [16].

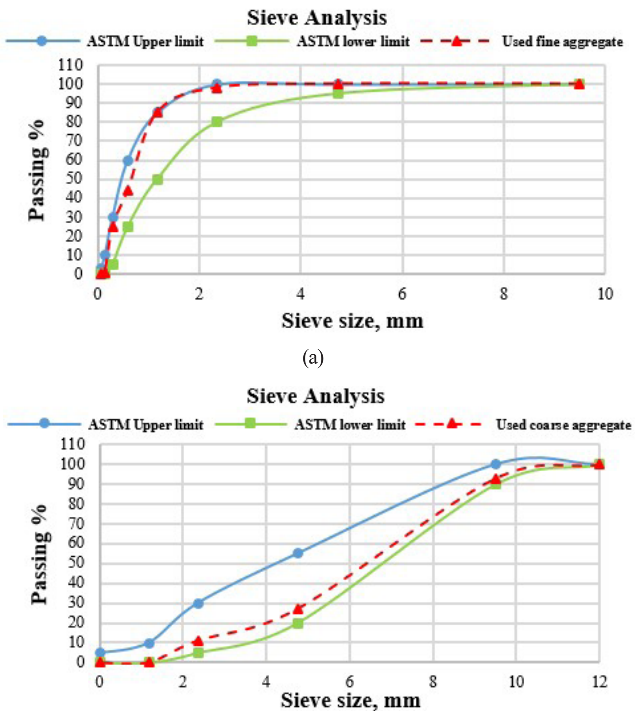


Fig. 1 Aggregate sieve analysis according to ASTM C33 [15], (a) Fine agregate, (b) Coarse agregate

Table 3 Chemical properties of fly ash

Component	Result %
SiO_2	48.43
Al_2O_3	17.15
Fe_2O_3	11.96
CaO	15.48
MgO	1.35
SO_3	0.82
LOI	1.47
TiO_2	2.68
K_2O	0.41
P_2O_3	0.4
Mn_2O_3	0.17
Na_2O	0.0019
SrO	0.2

2.4 High range water reducer admixture (HRWRA)

Concrete is mixed to a precise consistency using an additive called HRWRA that reduces the amount of water required by at least 12% [17]. At higher dosages, like 0.8% of cementitious materials, HRWRA could save up to 40% of water [18]. Because FRSCC needs to be made with a lower *w*/*b* ratio than regular concrete, which may have low workability, high-range water reducers, also known commercially as superplasticizers, can be added to the concrete mix to boost the workability of fresh concrete.

In the experimental program, a super-plasticizer (Flocrete SP90S) with a polycarboxylate base was utilized to increase the workability of fresh concrete.

2.5 Fibers

2.5.1 Polypropylene fiber

Monofilament PP fibers (SikaFiber PPM-12) used at the rate of 0.1% and 0.2% by volume in this study. Unlike steel fiber, PP fibers are not affected by weather conditions, alkaline environment in concrete or presence of moisture. Because there is no corrosion or rusting, the concrete made here should be durable and robust [19].

2.5.2 Steel fiber

A volume fraction of 0.1% and 0.2% of the straight high strength micro steel fibers (SDS-2213) were used.

2.6 Mix proportion design

In the study, as seen in Table 4, five different mixtures were used and a total of 90 cylinder samples were prepared. Table 4 shows the molds used, mixing and curing of concrete.

Table 4 Mix proportions of FRSCC mixes

Mixture	Cement kg/cm³	Fine Agg. kg/cm³	Fly Ash kg/cm³	Coarse Agg. kg/cm³	Water kg/cm³	Water After Correction kg/cm³	SP kg/cm³	W/P	PPF %	SF %
N	465.3	51.7	799.45	751.72	196.46	226.4	2.3	0.38	0	0
S1	465.3	51.7	799.45	751.72	196.46	226.4	2.3	0.38	0	0.1
S2	465.3	51.7	799.45	751.72	196.46	226.4	2.3	0.38	0	0.2
F1	465.3	51.7	799.45	751.72	196.46	226.4	3	0.38	0.1	0
F2	465.3	51.7	799.45	751.72	196.46	226.4	3.8	0.38	0.2	0

2.7 Sulfate and acid attacks

No accepted test procedure provides an estimate of the durability of concrete when subjected to chemicals. However, samples were exposed to 5% magnesium sulfate solution ($MgSO_4$) (50,000 mg/L) for 30 days at room temperature [20] and 5% sulfuric acid (H_2SO_4) solution for 30 days at room temperature. In addition, control samples for each mixture were simultaneously kept at ambient condition in the laboratory for 30 days for comparison. After the exposure time, tests were applied to determine the compressive strength and shear strength of the samples. Fig. 2 shows the samples after 1 month exposure to $MgSO_4$. Also, Fig. 2 shows the samples after 1 month exposure to H_2SO_4.

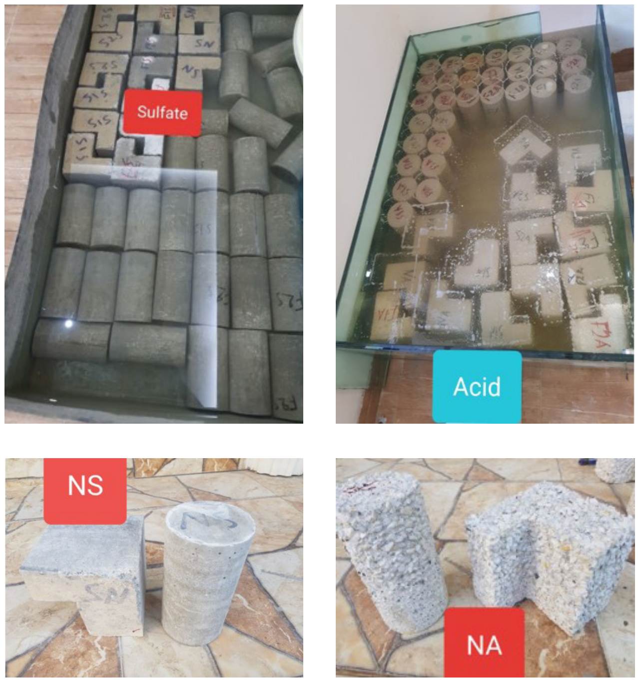


Fig. 2 Sample exposure to $MgSO_4$ and H_2SO_4 and condition after 1 month exposure

3 Experimental tests' results and discussion

3.1 Fresh state tests

In the study, EFNARC standards were used to determine the characteristics of the fresh FRSCC. Fig. 3 shows the tests performed on the fresh FRSCC and the results of the tests were given in Fig. 3.

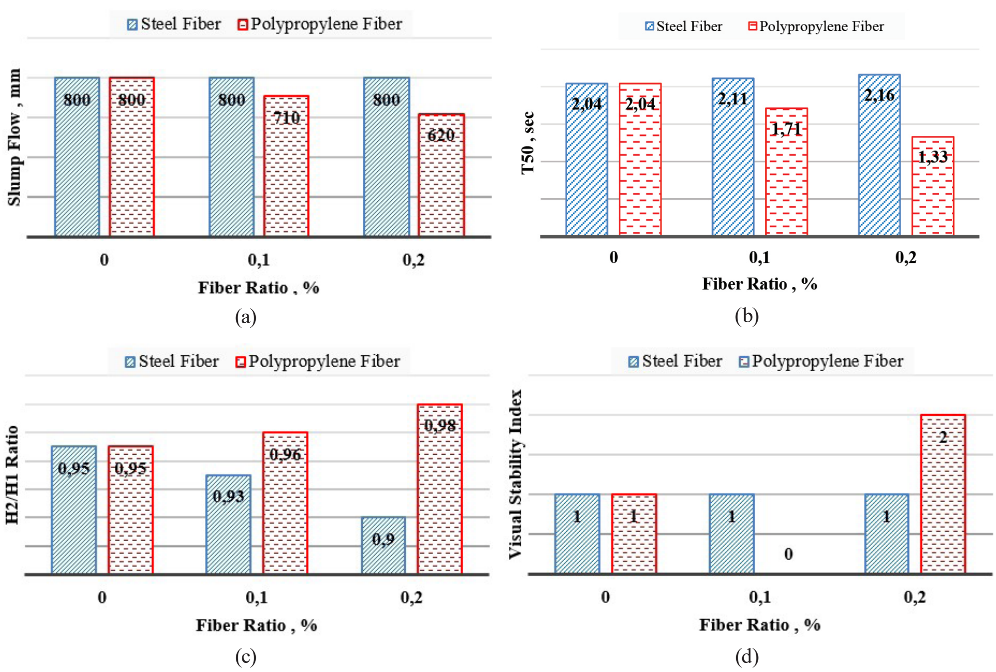


Fig. 3 Fresh state SCC test results, (a) Slump flow test results, (b) T50 time test results, (c) L-Box test results, (d) Visual stability index

The results show that the amount of PPF significantly affects the workability of FRSCC. Slump flow for the control samples was 800 mm, and it reduced correspondingly as PPF concentration increased, reaching 710 and 620 mm. This decrease in workability is expected because adding fibers to a concrete matrix affects the FRSCC's fresh state characteristics due to the large surface area of the fibers, which requires a larger volume of fluid phase to be adequately covered and lubricated, as well as the significant interlocking between the fibers and aggregates and inter-particle friction. In the literature, such as in Widodo's study [21], the tremendous influence of PPF on slump flow is widely documented. For samples of SF, the slump flow was 800 mm, the same as the control sample. Since our steel fiber ratio is low and they are the straight and smooth type, which do not impede the flow of concrete, this stability in workability in SF situations is expected. However, according to publications like that by Abbas [22], SFs in various shapes and vast quantities would typically induce a decline in slump but never as much as PPF.

T50 flow time was 2.02 seconds for control samples, and it dropped to 1.71 and 1.33 seconds as the PPF percentage rose. Because PPF typically increases viscosity and decreases workability, the increased superplasticizer dosage used to improve workability is what caused this decrease in T50 flow time [21] as known in literature. Therefore, superplasticizer dosage for SCC is necessary to obtain workable concrete. However, SCC mixtures with SF had no appreciable impact on T50 flow time (which climbed to 2.11 and 2.16 sec), as a result of the extremely low utilized fiber volume fraction. It takes a larger volume and a variety of shapes to really appreciate the impact of SF. The H2/H1 ratio of the control mix is 0.9. However, addition of PPF raised the H2/H1 ratio. Moreover, normally the presence of PPF in mixes limit the flow, but due to the increasing superplasticizer amount employed to tide over workability issues brought on by PPF, the opposite behavior occurred. Moreover, when the SF is increased to 0.2%, there is a slight (ineffective) reduction in the H2/H1 ratio; this ineffectiveness is caused by the factors the extremely low utilized fiber volume.

A visual stability index score of "0" indicated that there was no sign of segregation or bleeding in SCC mixture that contained 0.1% PPF. Nevertheless, the control mix and the SF mixtures (0.1% S1 and 0.2% S2) of SCC were stable, obtaining a visual stability index value of "1" for no signs of segregation but having moderate bleeding. The visual stability index values of these two concrete mixtures show excellent segregation resistance. However, the SCC mix containing 0.2% PPF displayed a mortar halo (>10 mm) and some minor bleeding. This can be the result of too much superplasticizer. With a visual stability index value of "2" this concrete was labeled as "unstable," indicating that it has a low segregation resistance.

Finally, the results of this study were compared to the workability limits of SCC established by EFNARC in 2005, the control mix and mixes contain SF were within the ranges of viscosity class VS1/VF1, slump flow class SF3, and passing ability PA2. Moreover, the passing ability class for both mixtures including PPF were PA2, and the viscosity class was VS2/VF2. Moreover, while the mixtures containing 0.1% PPF had a slump flow class of SF2, the mixture containing 0.2% PPF had a slump flow class of SF1.

3.2 Hard state tests' results and discussion

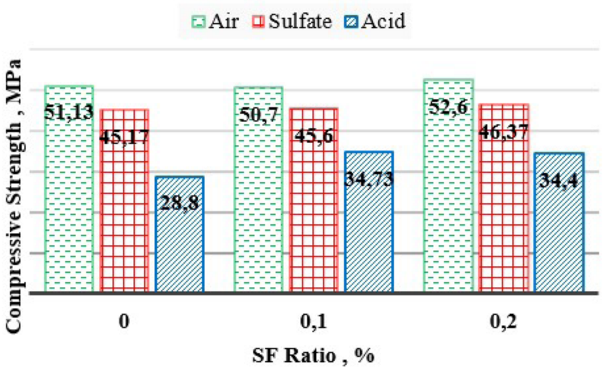
3.2.1 Compressive strength test

Compressive strength tests were carried out with cylindrical specimens of 100 mm × 200 mm in accordance with ASTM C39 [23], using the 3000 kN capacity pressure strength device shown in Fig. 4. Tests were performed according to ASTM C39 at 0.15 MPa/sec and the average of three-cylinder samples was taken to determine the compressive strength of each sample. In addition, compressive strength test results were given in Fig. 5(a) and Fig. 5(b).

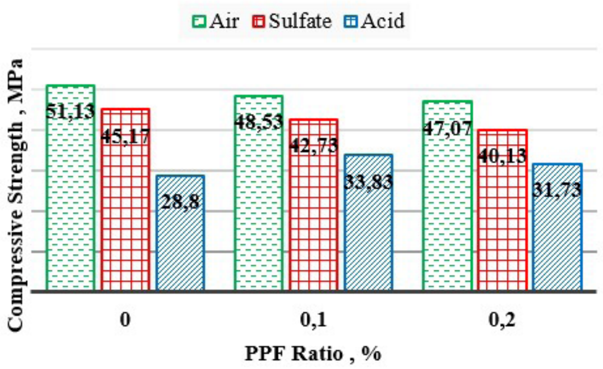
According to the findings, it can be concluded that adding SF to SCC enhances fiber volume fractions and compressive strength for all combinations. However, it is typical for 0.1% SF ratio to have a minor drop in compressive strength in an air environment. This is because SF ratios lower than 0.3% volume ratio make it difficult to clearly see an increase in compressive strength [10]. But the 0.2% SF ratio increased the compressive strength by about 3%, as shown in Fig. 5(a).

(a) (b)

Fig. 4 Compressive strength tests, (a) Testing machine, (b) Test cylinder specimen for compressive strength



(a)



(b)

Fig. 5 Compressive strength test results, (a) Compressive strength of samples with SF in different environments, (b) Compressive strength of samples with PPF in different environments

In the sulfated environment example, $MgSO_4$ reduced the samples' compressive strength by 11.66, 10.06 and 11.84% for SF fractions of 0, 0.1 and 0.2%, respectively, as demonstrated in Fig. 5(a). However, also in the case of sulfate, SF helped to increase the compressive strength of the sulfate medium by 1% and 2.66%, respectively, for SF ratios of 0.1% and 0.2% compared to the control sample. This improvement in the sulfate environment of SF was also observed by Elhwary et al [24].

In the acid environment condition, H_2SO_4 lowered the compressive strength of samples by 43.67, 31.5 and 34.6% for SF fractions of 0, 0.1 and 0.2%, respectively. However, for SF ratios of 0.1 and 0.2%, respectively, SF assisted in improving compressive strength relative to the control sample by 20.59 and 19.44%. This improvement in acid media by SF also reported by Kos et al. [25] and Yu et al. [26].

The ability of SF to increase cohesion among the components of the concrete mixture, provide additional strength with resistance to concrete under the influence of applied loads, and confinement influence of fiber that increases the stiffness of concrete can all be attributed to the improvement in compressive strength with the addition of SF in these media.

In general, as noted in publications such as the one described by Elhwary et al. [19], PPF did not significantly improve compressive strength when compared to SF, as demonstrated Fig. 5(b). But according to Elhwary et al. [24], Gencel et al. [19] and Widodo [21], there was a minor (small) gain in compressive strength for lower ratios of PPF. In this investigation, it can be deduced that excessive superplasticizer amount, as stated by Benaicha et al. [27], is the main cause of reducing compressive strength in air and sulfate cases.

In the acid environment condition, H2SO4 lowered the compressive strength of specimens by 43.67, 30.29, and 32.59% for PPF ratios of 0, 0.1, and 0.2%, respectively. However, according to the results obtained, the effect of PPF on an acidic environment is exciting. Because, comparing the sample with the control sample without fiber, the compressive strength increased by 17.47% and 10.17% for PPF content of 0.1% and 0.2%, respectively. In addition, in the case of acid, PPF can be close or identical to SF in resistance to acid attack, as reported by Kos et al. [25].

3.2.2 Direct shear strength test

In the literature, there are various methods to determine the shear strength of concrete. However, they appear to be not practical due to their deficiencies and divergence as samples have two shear planes as well as practically; it is not possible that two plane collapses at the exact moment for a sample never occurred [28]. In this study, the method proposed by Bairagi and Modhera [29] was used to determine the shear strength, as the model was subjected to pure shear force. A 150 mm high, 90 mm wide and 60 mm deep block was placed inside a 150 mm cube to make the L-shaped specimen used in this study. The plates were placed on top of the L-shaped sample so that the plate measuring 150 × 85 × 10 mm^3 and the solid portion measuring 150 × 150 × 90 mm^3 were on the side. The plate was placed adjacent to the 22 mm size bar. As shown in Figs. 6 and Fig. 7, a second bar with a diameter of 12 mm was placed on the bottom plate and a second plate measuring 150 × 110 × 10 mm^3 was placed on top of the two bars. The model was tested using a 3000 kN capacity compression tester at 140 kg/cm^2 per minute.

In this study, shear strength at room temperature was investigated. At the end of the exposure period, direct shear tests were performed on three L-shaped samples and the results were found. In addition, the shear stress just above the segment was determined using the following equation Eq (1).

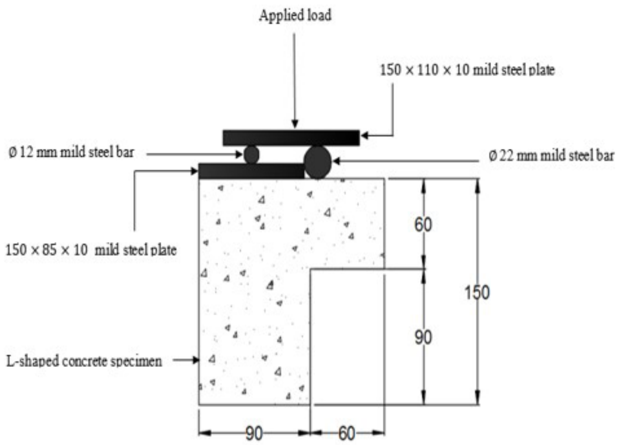


Fig. 6 Schematic illustration of shear test arrangement

Fig. 7 Testing arrangement and tested samples

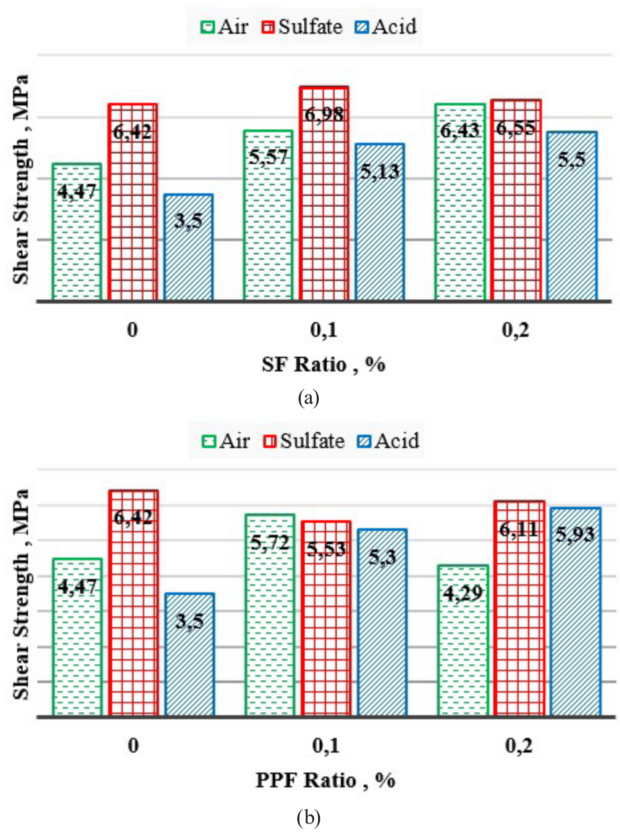


Fig. 8 Shear strength test results, (a) Shear strength of samples with SF in different environments, (b) Shear strength of samples with PPF in different environments

$$\tau = \frac{Pu}{b \times d} \quad (1)$$

Where:

P_u is the maximum applied load at failure of the specimen,

τ is shear stress,

d with b are the size dimensions of the shear plane.

The direct shear strength results under various environmental conditions, fiber types and fraction volumes were given in Fig. 8(a) and Fig. 8(b). Due to the significant dispersions of the fibers, when the concrete cracked, the fiberless concrete abruptly split off, which improved the bridging activity in the concrete matrix.

Generally, SF improved shear strength, as reported by Barr [30], Narayanan and Darwish [31], Nanni et al. [32] Noghabai [33], Awrahman [9]. In the case of the air environment, SF increased the shear strength of the samples by roughly 24.61 and 43.85% for ratios of 0.1 and 0.2%, respectively, as indicated Fig. 8(a).

In the sulfate environment condition, $MgSO_4$ improved the shear strength of specimens. Since shear friction should increase if normal tension and roughness increase, concrete's response to shear is distinct from that to tensile stress, hence this may be occurred in the early stages of sulfate exposure [34]. Brueckner et al [35] evaluated the effect of taumasite sulfate attack on skin friction at the concrete interface. They discovered that the thaumasite form in close contact with the concrete was the primary cause of increased skin friction. According to their research, this development was due to local expansion pressure brought on by the sulfate product thaumasite. This pressure has the wonderful ability to act as a normal tension perpendicular to the slip plane (interface) to drive friction at these locations. In addition, this chemical treatment caused the roughness of the interface to increase, which in turn increased the frictional force along such failure points [34]. Recently, Pastor et al. [36] reported similar findings in their research on skin friction modification due to sulfate attack. Rarely published are the shear failure mode and failure criteria of sulfate-attacked concrete under direct shearing [35].

Moreover, in the sulfate case as well, SF contributed to an increase in shear strength of 8.72% and 2.03%, respectively, as compared to the control sample, as reported by Taqi et al. [37].

In the acid environment case, H_2SO_4 reduced the shear strength of samples by 21.7, 7.9, and 14.46% for the fiber volume fractions of 0, 0.1 and 0.2%, respectively. However, H_2SO_4 improved the shear strength of samples by 46.57 and 57.14% for SF fractions of 0.1 and 0.2%, respectively. This increment of shear strength in acid media was also reported by Badagha and Modhera [38].

In general, PPF enhanced the shear strength. In the air environment condition, while PPF increased the shear strength of samples by about 27.96% for PPF ratio of 0.1%, the shear strength decreased by 4.03% for PPF fraction of 0.2% compared to the control sample. This slight drop in shear strength may be owing to the uncertainty of the mixture or excess superplasticizer, as noticed by Ahmed et al. [39].

In the sulfate environment case, $MgSO_4$ boosted the shear strength of the samples, as shown in Fig. 8(b). This may have happened in the early ages of sulfate exposure due to factors previously discussed for SF condition. However, in the sulfate case, shear strengths of specimens including PPF were 13.86 and 4.83% lower than the control sample for PPF ratios of 0.1 and 0.2%, respectively. This decrease may be caused by the excessive usage of superplasticizer or according to the literature, the sulfate attacks actually manifest after 90 days or more, thus additional research is required to determine the role of fiber in the long-term attack. Furthermore, a significant 10.49% increase in shear strength was seen when PPF ratio was increased from 0.1% to 0.2%, which may lead us to believe that PPF in a sulfate environment can also boost shear strength, as reported by Hegde et al. [40].

In the acid environment condition, H2SO4 had a negative effect on the shear strength of the samples by 21.7 and 7.9% for PPF fractions of 0 and 0.1%, respectively. Additionally, it was thought that there was a mistake for the 0.2% PPF ratio so it was not reported the decreased percentage because this decrease could be the result of the mix's instability. But even in the acid case, PPF increased the shear strength by 51.43 and 69.43% for PPF of 0.1% and 0.2%, respectively, in comparison to the control sample.

3.2.3 Split tensile strength test

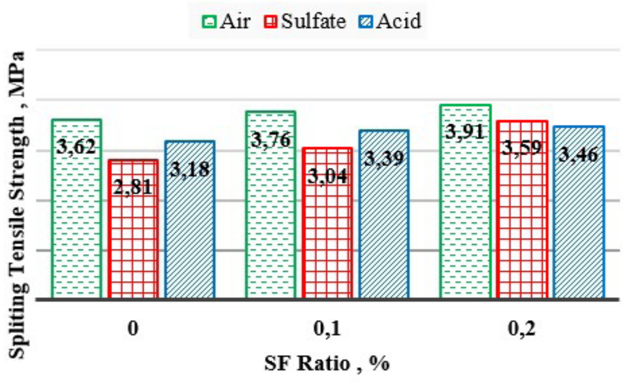
According to ASTM C496 [41] on the 100 × 200 mm cylinders, the concrete splitting tensile strength was measured using the same machine used for the compression test at the suggested loading rate of 689 kPa/min (689 to 1380 kPa/min). One test cylinder is shown in Fig. 9(a) and Fig. 9(b) before and after for testing. At the conclusion of the exposure time, the average outcome of three tested cylinders was determined. In addition, split tensile test results in different environment were given in Fig. 10.

The fiberless concrete burst off in an instant when the concrete cracked. Because of the fibers' high dispersions, the concrete matrix's bridging activity was improved. The fiber concrete cracked but did not entirely separate.

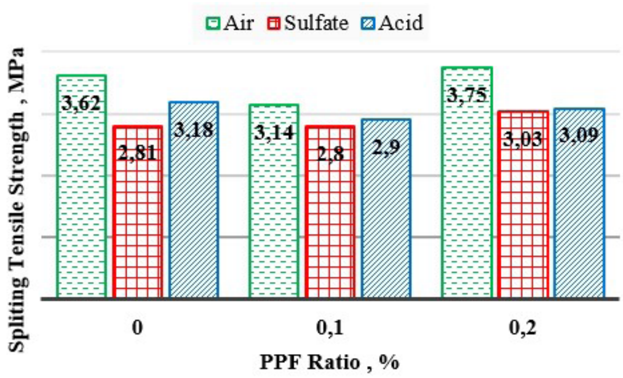
According to the results, usually, SF improved the tensile strength. In the case of the air environment, steel fiber increased the splitting tensile strength of samples by about 4 and 8% for fiber volume fractions of 0.1 and 0.2%,

(a) (b)

Fig. 9 Split tensile strength tests, (a) Before test, (b) After test



(a)



(b)

Fig. 10 Split tensile strength test results, (a) Steel fiber splitting tensile strength in different environment, (b) Polypropylene fiber splitting tensile strength in different environment respectively, as shown in Fig. 10(a). Elhwary et al. [24] also reported that SF improved the splitting tensile strength in the air (control) media.

In the sulfate case, $MgSO_4$ reduced the splitting tensile strength of samples by 22.38, 19.15, and 8.18% for SF fractions of 0, 0.1, and 0.2%, as shown in Fig. 10(a). Haufe and Vollpracht [42] noticed that when exposed to sulfate attack, concrete tensile strength reduced. However, in the sulfate case, SF increased the splitting tensile strength by 8.19% and 27.76% compared to the control sample for SF volumes of 0.1 and 0.2%, respectively, as noticed by Kos et al. [25].

In the Acid environment, H_2SO_4 reduced the splitting tensile strength of samples by 12.16, 9.84, and 11.51% for SF fractions of 0, 0.1, and 0.2%, respectively. However, as reported by Niu and Wang [43], SF increased the splitting tensile strength by 6.6 and 8.81% over the control sample for SF volumes of 0.1 and 0.2%, respectively.

The addition of SF to these medias improved the splitting tensile strength for the following reasons: 1-the connection between the components of the mixture is strengthened, 2-cracks are delayed and their width is reduced, 3-the SF play an important role in the section's ability to increase bearing and produce additional resistance as linking bridges in the crack area.

In general, PPF did not have a significant increase in the splitting tensile strength when compared to SF, as reported in the literature by Elhwary et al. [24]. However, Widodo [21] reported an increase in the split tensile strength of PPF. In this study, it can be concluded that the main reason for reducing splitting tensile strength in all environment cases when PPF ratio is equal to 0.1% is due to excessive superplasticizer content, which can lead to a drop in compressive strength, as reported by Benaicha et al. [27]. However, aside from the negative effect of too much superplasticizer, it can be seen a significant improvement in the splitting tensile strength when PPF volume ratio was increased to 0.2%. Except in the case of acid, fiber act as a bridge between microcracks, preventing them from spreading. Transferring tensile stress to the fiber can prevent microcracks from growing and greatly increase the splitting tensile strength of concrete [19]. In the air environment, PPF increased the splitting tensile strength of samples by approximately 3.59% compared to the control sample for PPF fraction of 0.2%.

In the sulfate environment, $MgSO_4$ reduced the splitting tensile strength of samples by 22.38, 10.83, and 19.2% for PPF ratios of 0, 0.1 and 0.2%, respectively. However, in the sulfate case, PPF increased the splitting tensile strength by 7.83% compared to the control sample for PPF ratio of 0.2%.

In the acid environment, $H2SO_4$ reduced the splitting tensile strength of samples by 12.16, 7.64, and 17.6% for PPF volume fractions of 0, 0.1 and 0.2%, respectively. Moreover, in the acid case, PPF had no effect on splitting tensile strength when compared to the control sample.

4 Discussions

FRSCC generally improved mechanical properties and durability. Traditional transverse shear reinforcement can be wholly or partially replaced by adding SFs. Polypropylene fibers should not be used for structural reinforcement, producing thinner sections and increasing joint span. However, it gives SCC good durability and slight mechanical properties improvement.

As a result of the study, generally better mechanical performance of the samples with SF was obtained in air, sulfate and acid conditions than the samples with PPF. In addition, better results were obtained as the SF and PPF ratios in the samples increased. However, what is interesting is that PPF exhibits an unexpected resistance to acid environment because PPF does not dissolve after acid attack. After the acid effect, no traces of SF dissolution were found on the concrete surface.

5 Conclusions

In the study, some properties of SCC were investigated in three different environments using two different ratios (0.1% and 0.2%) of SF and PPF. In this section, the fresh and cured properties of all mixtures were examined compared to the control mixture, and the following conclusions can be drawn from the test results of this study:

- While SF with a reduced volume percentage had no negative effects on workability parameters including filling ability, passing ability, and segregation, PPF reduced the slump flow. Therefore, when using more than 0.1% PPF, an excessive amount of superplasticizer was used to meet the process ability had positive effect requirements of the SCC.
- SF inclusion in SCC often had positive effect on the compressive strength in all exposure cases. While, a 0.1% volume fraction of SF did not show any improvement, a 0.2% volume fraction of SF showed a significant increase. PPF decreased the compressive strength for all mixtures. It was come to the conclusion that the excess superplasticizer ratio added to the mixture in order to address workability issues created by the addition of polypropylene fiber is the main source of our losses in compressive strength, particularly for a volume fraction of 0.1%.

- Increasing the volume percentage of SF in all exposure led to correspondingly enhanced tensile strength in all SFs. However, while for PPF of 0.1% splitting strength decreased for all blends, for PPF of 0.2% splitting tensile increased. These decreases were caused by an excess of superplasticizer rather than a fiber-effect.
- In all exposure conditions, SCC that contains SF improved in shear strength proportionally to the volume percent of SF added. This may help to explain why a lot of research came to the conclusion that typical transverse shear reinforcement could be entirely or partially replaced by the use of SFs.
- In the air environment, while PPF of 0.1% helped the samples' shear strength increased, for 0.2% PPF percentage the shear strength dropped. In the case of sulfate, the shear resistance of SCC samples containing PPF was reduced. It can be concluded that it decreases due to excessive superplasticizer. Moreover, when the ratio of PPF in the SCC mixture was increased from 0.1% to 0.2%, it increased the shear strength.
- In the acid scenario, PPF increased shear strength. Because, under direct shear stress, the concrete containing no fibers abruptly failed once the concrete fractured; adding SF and PPF improved the bridge-building action in the concrete matrix, so showed splitting but did not completely separate.
- It was discovered that SF generally enhanced the qualities of SCC more so than PPF. Moreover, it is interesting that PPF gave us unexpected resistance to an acid environment, because PPF did not dissolve in acid following the attack. After the acid attack, it was found no sign of the SF on the concrete's surface, indicating that they had been dissolved.

References

[1] ACI Committee 318 "Building code requirements for structural concrete (ACI 318-11) and commentary", American Concrete Institute, Farmington Hills, MI, USA, 2011.

[2] Nawy, E. G. "Reinforced Concrete: A Fundamental Approach", Prentice Hall, 2009. ISBN 0132417030

[3] Wang, C.-K., Salmon, C. G., Pincheira, J. A. "Reinforced concrete design", Wiley, 2007. ISBN: 0471262862

[4] Nilson, A. H., Darwin, D., Dolan, C., W. "Design of concrete structures", McGraw-Hill, 2010. ISBN 0071311394

[5] Mohammedameen, A., Gülşan, M. E., Alzeebaree, R., Çevik, A., Niş, A. "Mechanical and durability performance of FRP confined and unconfined strain hardening cementitious composites exposed to sulfate attack", Construction and Building Materials, 207, pp. 158–173, 2019. https://doi.org/10.1016/j.conbuildmat.2019.02.108

[6] Sarsam, K. F., Al-Attar, T. S., Jumah, G. G. "Direct Shear Behavior of Carbon Fiber Reinforced Self-Compacting Concrete", Engineering and Technology Journal, 32(10), pp. 2491-2513, 2014.

[7] Khayat, K. H. "Workability, testing, and performance of self-consolidating concrete", ACI Materials Journal, 96(3), pp. 346–353, 1999. https://doi.org/10.14359/632

[8] Khalilpasha, M. H., Nik, A. S., Omran, O. L., Kimiaeifard K., Molla, M. A. "Sustainable development using recyclable rubber in Self-Compacting Concrete", In: Third International Conference on Construction in Developing Countries (ICCIDC–III), Advancing Civil, Architectural, and Construction Engineering & Management, Bangkok, Thailand, 2012, pp. 580–585. ISBN 1-884342-02-7

[9] Awrahman A. H. "Direct Shear Strength of Fiber Reinforced Self Compacting Concrete Under Acid and Sulfate Attack", MSc Thesis, Gaziantep University, 2023.

[10] Siddique, R. "Self-compacting concrete: materials, properties and applications", Woodhead Publishing, 2019. ISBN 9780128173701 https://doi.org/10.1016/C2018-0-01683-7

[11] Ganesh, B. K. and Pavan, K. D. "Behavior of Glass Fiber Reinforced Cement Composites", presented at the International Conference on Fiber composites, High Performance Concretes and Smart Materials, Chennai, India, Jan. 8–10, 2004.

[12] EFNARC "The European guidelines for self-compacting concrete", Flums, Switzerland, Rep. SCC 028, 2005.

[13] ACI Committee 237 "Self-Consolidating concrete", American Concrete Institute, Farmington Hills, MI, USA, 2007.

[14] I.O.S 5/2019 "Iraqi Standard Specification, Portland cement", Central Organization for Standardization and Quality Control, Baghdad, Iraq, 2019.

[15] ASTM "ASTM C33/C33M-18 Standard Specification for Concrete Aggregates", West Conshohocken, PA USA, 2018. https://doi.org/10.1520/C0033_C0033M-18

[16] Topçu, İ. B., Bilir, T. "Experimental investigation of some fresh and hardened properties of rubberized self-compacting concrete", Materials & Design, 30(8), pp. 3056–3065, 2009. https://doi.org/10.1016/j.matdes.2008.12.011

[17] ASTM "C1611/C1611M-05 Standard Test Method for Slump Flow of Self-Consolidating Concrete", West Conshohocken, PA, USA, 2005. https://doi.org/10.1520/C1611_C1611M-05

[18] ACI Committee 212.3R-16 "Report on Chemical Admixtures for Concrete", American Concrete Institute, Farmington Hills, MI, USA, 2016. ISBN: 978-1-942727-80-4

[19] Gencel, O., Ozel, C., Brostow, W., Martínez-Barrera, G. "Mechanical properties of self-compacting concrete reinforced with polypropylene fibres", Materials Research Innovations, 15(3), pp. 216–225, 2011. https://doi.org/10.1179/143307511X13018917925900

[20] Amin, M. M., Jamaludin, S. B., Pa, F. C., Chuen, K. K. "Effects of magnesium sulfate attack on ordinary Portland cement (OPC) mortars", Portugaliae Electrochimica Acta, 26(2), pp. 235–242, 2008. https://doi.org/10.4152/pea.200802235

[21] Widodo, S. "Fresh and hardened properties of Polypropylene fiber added Self-Consolidating Concrete", International Journal of Civil and Structural Engineering, 3(1), pp. 85–93, 2012. https://doi.org/10.6088/ijcser.201203013008

[22] Abbas, A.-A. "The effect of steel fiber on some mechanical properties of self-compacting concrete", American Journal of Civil Engineering, 1(3), pp. 102–110, 2013. https://doi.org/10.11648/j.ajce.20130103.14

[23] ASTM "ASTM C39/C39M-21 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens", West Conshohocken, PA USA, 2021. https://doi.org/10.1520/C0039_C0039M-21

[24] Elhwary, E. I. N., Elsafoury, A. H. H., Ahmad, S. S. E. "Assessment of High-Performance Fiber Reinforced Concrete (HPFRC) Durability Due to Exposing to Different Environmental Media", Journal of Civiltech, Innovations in Civil Engineering and Technology, 3(2), pp. 93–114, 2021.

[25] Kos, Ž., Kroviakov, S., Kryzhanovskyi, V., Hedulian, D. "Strength, Frost Resistance, and Resistance to Acid Attacks on Fiber-Reinforced Concrete for Industrial Floors and Road Pavements with Steel and Polypropylene Fibers", Materials, 15(23), 8339, 2022. https://doi.org/10.3390/ma15238339

[26] Yu, J., Qiao, H., Zhu, F., Wang, X. "Research on damage and deterioration of fiber concrete under acid rain environment based on GM(1,1)-Markov", Materials, 14(21), 6326, 2021. https://doi.org/10.3390/ma14216326

[27] Benaicha, M., Alaoui, A. H., Jalbaud, O., Burtschell, Y. "Dosage effect of superplasticizer on self-compacting concrete: correlation between rheology and strength", Journal of Materials Research and Technology, 8(2), pp. 2063–2069, 2019. https://doi.org/10.1016/j.jmrt.2019.01.015

[28] Kurup, A. R., Kumar, K. S. "Effect of recycled PVC fibers from electronic waste and silica powder on shear strength of concrete", Journal of Hazardous, Toxic, and Radioactive Waste, 21(3), 06017001, 2017. https://doi.org/10.1061/(ASCE)HZ.2153-5515.0000354

[29] Bairagi, N. K., Modhera, C. D. "Shear strength of fibre reinforced concrete", Indian Concrete Institute Journal, 1(4), pp. 47–52, 2001.

[30] Barr, B. "Fracture characteristics of FRC materials in shear", ACI Special Publication, 105, pp. 27–54, 1987. https://doi.org/10.14359/2017

[31] Narayanan, R., Darwish, I. "Bond Anchorage of Pretentioned FRP Tendon at Force Release", ASCE Journal of Structural Engineering, 180(10), pp. 2837–2854, 1987.

[32] Nanni, A., Tanigaki, M., Hasuo, K. "Bond Anchorage of Pretensioned FRP Tendon at Force Release", ASCE Journal of Structural Engineering, 118(10), pp. 2837–2854, 1992. https://doi.org/10.1061/(ASCE)0733-9445(1992)118:10(2837)

[33] Noghabai, K. "Beams of fibrous concrete in shear and bending: experiment and model", Journal of Structural Engineering, 126(2), pp. 243–251, 2000. https://doi.org/10.1061/(ASCE)0733-9445(2000)126:2(243)

[34] Zhang, Z.-Y., Zhou, J.-T., Zou, Y., Yang, J., Bi, J. "Change on shear strength of concrete fully immersed in sulfate solutions", Construction and Building Materials, 235, 117463, 2020. https://doi.org/10.1016/j.conbuildmat.2019.117463

[35] Brueckner, R., Williamson, S. J., Clark, L. A. "The effects of the thaumasite form of sulfate attack on skin friction at the concrete/clay interface", Cement and Concrete Research, 42(2), pp. 424–430, 2012. https://doi.org/10.1016/j.cemconres.2011.11.009

[36] Pastor, J. L., Ortega, J. M., Climent, M. A., Sánchez, I. "Skin friction coefficient change on cement grouts for micropiles due to sulfate attack", Construction and Building Materials, 163, pp. 80–86, 2018.

[37] Taqi, F. Y., Mashrei, M. A., Oleiwi, H. M. "Experimental study on the effect of corrosion on shear strength of fibre-reinforced concrete beams", Structures, 33, pp. 2317–2333, 2021. https://doi.org/10.1016/j.istruc.2021.06.006

[38] Badagha, D., Modhera, C. D. "An experimental approach to investigate effects of curing regimes on mechanical properties and durability of different fibrous mortars", Advances in Structural Engineering, Springer, 2015, pp. 1917–1929. ISBN 978-81-322-2186-9 https://doi.org/10.1007/978-81-322-2187-6_148

[39] Ahmed, S., Bukhari, I. A., Siddiqui, J. I., Qureshi, S. A. "A study on properties of polypropylene fiber reinforced concrete", In: Proceedings of the 31st Conference on Our World in Concrete and Structures, Singapore, 2006, pp. 63–72. ISBN 9789810555603

[40] Hegde, G., Prakash, K. B., Kori, J. G. "An Investigation on the Durability Properties of Textile Fibre Reinforced Concrete under Sulphate attack", International Research Journal of Engineering and Technology, 6(6), pp. 3069-3079, 2008.

[41] ASTM "ASTM C496/C496M-17 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens", West Conshohocken, PA USA, 2017. https://doi.org/10.1520/C0496_C0496M-17

[42] Haufe, J., Vollpracht, A. "Tensile strength of concrete exposed to sulfate attack", Cement and Concrete Research, 116, pp. 81–88, 2019. https://doi.org/10.1016/j.cemconres.2018.11.005

[43] Niu, D., Wang, Y. "Neutralization of steel fiber reinforced concrete under multiple influential factors", Journal of Earthquake and Tsunami, 7(3), 1350015, 2013. https://doi.org/10.1142/S1793431113500152