Case Studies in Construction Materials 16 (2022) e00970

Contents lists available at ScienceDirect

Case Studies in Construction Materials

journal homepage: www.elsevier.com/locate/cscm

Investigation of mechanical properties of red pine needle fiber reinforced self-compacting ultra high performance concrete

Mustafa Tolga Cogurcu [*,1]

Konya Technical University, Faculty of Engineering and Natural Sciences, Department of Civil Engineering, Konya, Turkey

ARTICLE INFO

Keywords:
Pine needle fiber
Natural fiber
Self-compacting concrete
Mechanical properties
Ultra high performance concrete

ABSTRACT

With the increasing effects of global warming, the use of natural materials in engineering studies is increasing. In engineering construction, on the other hand, the use of natural fibers as concrete additives in order to reduce carbon emissions and protect the green environment is the focus of the studies. It is possible to increase ductility with the use of fiber in self-compacting ultra high performance concrete. The use of natural fibers provides an environmentally friendly approach. Therefore, in this study, the effect of red pine needles on the mechanical properties of self-compacting ultra high performance concrete was investigated. Pine needles were divided into 30, 40 and 50 mm length. The red pine needles were purified from organic matter with alkaline solution. It was added into the self-compacting ultra high performance concrete at the rates of 0.25%, 0.50%, 0.75% and 1.00% by volume. Slump-flow test, v-funnel test, compressive strength test, flexural strength test, freeze-thaw test, sulfate attack test were applied to examine the mechanical properties of the samples. In the sample with a length of 30 mm and a fiber content of 0.50%, the slump-flow test results decreased from 738 mm to 723 mm compared to the reference sample. According to the V-funnel test results, the closest results to the reference sample were obtained. The sample with a length of 30 mm and a fiber content of 0.50% provided a 15.6% increase in the 28-day compressive strength. On the other hand, the flexural strength increased from 8.60 MPa to 22.46 MPa according to the reference sample. In the sulfate attack test and freeze-thaw test, the closest results to the reference sample were obtained with the 30 mm length sample with 0.50% fiber content. With the results obtained, it was seen that the use of pine needles as a natural fiber in self-compacting concrete was appropriate.

1. Introduction

Concrete is the most preferred construction material in the field of civil engineering all over the world due to its advantages such as low cost, easy access to the material and durability [1]. Energy dissipation of structures under dynamic loads is an important feature. Therefore, the materials used must exhibit ductile behavior and high energy absorption. However, concrete is a brittle material due to its low tensile and flexural strength and poor toughness properties [2]. In addition, environmental pollution is increasing with the increase in the use of cement. There is a significant amount of carbon emissions in cement production. Therefore, studies to improve the mechanical properties of concrete by limiting the use of cement are increasing [3–6]. Studies continue around the world to improve

* Corresponding author.
E-mail address: mtcogurcu@ktun.edu.tr.
[1] ORCID: 0000–0002-2487–797X

https://doi.org/10.1016/j.cscm.2022.e00970
Received 28 January 2022; Received in revised form 14 February 2022; Accepted 19 February 2022
Available online 22 February 2022

the ductility of concrete and increase toughness. It is possible to improve ductility and toughness with the composite material obtained by adding fiber to concrete [7–10].

Adding fiber to concrete is one of the effective method to increase the mechanical properties of concrete [9,11–13]. Adding fiber to concrete is not a new subject. In the last five decades, many studies have been carried out on fiber reinforced concrete [14]. The fibers interact with the concrete through adhesion, friction and mechanical anchoring [15]. Cracks in concrete at advanced damage levels cause strength losses and a decrease in toughness. Fibers act as crack arresters and increase mechanical properties such as ductility, toughness and impact resistance after cracking [1,2]. Fibers are extremely important as they assure the safety and integrity of building elements before building element is completely failure [16]. In recent years, various methods such as fiber surface modification [17, 18], making scratches on fiber surfaces with sandpaper [19], coating the surfaces of fibers [20,21] have been applied for the development of fiber reinforced concrete. In this way, the tensile strength and energy absorption capacity of the fibers are increased. Steel, glass and carbon fibers are generally used in concrete. Contrary to the advantages of fibers, production and modification have some disadvantages such as material costs and high energy consumption [2]. In particular, studies conducted in recent years have revealed findings that industrial fibers are harmful to human health [22]. In addition, developing countries are looking for alternative low-cost fibers due to the expensive production of industrial fibers. This situation leads researchers to cheaper, environmentally friendly materials. In this way, studies on the use of natural fibers in composite materials have emerged [23,24].

One of the first studies to use natural fibers to improve mechanical properties in composite materials is the Australian research [22]. Natural fibers have been used as a substitute for asbestos in fiber cement products. In recent studies, the use of natural fibers as concrete reinforcement has been examined [2,25]. Coutts and Ni extensively studied the effects of bamboo fibers on concrete [26]. Sierra Beltran, on the other hand, studied the use of wood fibers as reinforcement in concrete [27]. In addition, banana, sisal, hemp, and flax, eucalyptus, and coconut have also been used as fibers in concrete mix in different studies [28–34]. Studies have shown that natural fibers have an improving effect on mechanical properties. However, in some studies, it has been observed that treated natural fibers are more effective than untreated natural fibers if they are purified from organic substances by treating [23,35]. Yan et al. treated the coconut fiber in 5% wt NaOH solution. As a result, it was seen that it contributed significantly to the mechanical properties [36]. Ali et al. soaked the coconut fiber in boiling water. It was observed that there were improvements in the mechanical properties of the fibers kept in boiling water [37]. Long and Wang treated the pine needles by soaking them in a 2% NaOH solution, either in boiled or non-boiled water. Saad et al. prepared a chemical solution with 25 g of NaOH and 1 L of water. Banana and palm fibers were soaked in solution for 4 h [38]. As a result, it was observed that the alkaline treated fibers exhibited better mechanical properties [23].

In structural elements with high reinforcement ratio, it is very difficult to place the concrete in the formwork [39]. Even if compacting is achieved by applying vibration, the voids cannot be filled completely. Therefore, the voids in the concrete cause a decrease in strength [1]. Self compacting concrete (SCC) is a significant development in concrete technology. Studies on SCC started in the 1980 s [40]. In the following years, studies on the subject continued in many countries [41–43]. SCC does not need vibration when compacted in the formwork. SCC easily take shape of the formwork without vibration, even in structural elements with very dense reinforcement bars [44,45]. In this way, it increases the bond strength by completely covering the reinforcement bars. Since the water/cement ratio is low, concrete strength is higher than conventional concrete. SCC has many technical and economic contributions. Its advantages can be further expanded, especially with fiber supplementation [46]. Many mechanical properties of concrete such as ductility, toughness, stiffness and crack propagation control can be improved with fiber reinforced SCC [47,48].

In this study, red pine needles were used as self compacting ultra high performance concrete (SCUHPC) fiber reinforcement. Red pine is a native pine species in the Eastern Mediterranean region. Ecologically and economically, it is one of the most important forest tree species in Turkey and is dominantly distributed in Turkey [49]. There are limited number of studies on the use of pine needles as a fiber reinforcement in concrete. Daxiang et al. conducted a study on the use of pine needle reinforced concrete in cold regions [50]. Mashri et al. investigated the mechanical properties of conventional concrete with pine needle additives [51]. Abdin and Khitap investigated the mechanical properties of pine needle fiber reinforced cementitious mortar [52]. The highest compressive strength values were obtained in the samples in which length of 50 mm fibers were added with 1% by weight. Long and Wang investigated the effect of pine needles treated by various methods on the mechanical properties of concrete [23]. There are many studies on the use of natural fibers in concrete. However, studies on the red pine needles reinforced concrete are very limited. Especially in ultra-high performance self-compacting concretes, pine needle additive is included in a very limited number of studies. In this study, the mechanical properties of red pine needle reinforced SCUHPC were investigated and the effect of natural fibers on SCUHPC was investigated. In this way, it is aimed to use natural fibers instead of human-made fibers in SCUHPC.

Table 1
Chemical and physical properties of cement.

Chemical properties (%)		Physical and mechanical properties	
SO_3	2.84	Initial setting time (min.)	137
MgO	3.76	Final setting time (min.)	179
CaO	62.96	2-days compressive strength (MPa)	25.4
SiO_2	17.99	28-days compressive strength (MPa)	51.8
K_2O	0.35	Specific gravity (g/cm^3)	3.12
Na_2O	0.17	Specific surface (cm^2/g)	3674
Al_2O_3	4.43		
Fe_2O_3	3.35		
Cl^-	0.0211		

2. Materials and methods

2.1. Materials

CEM I 42.5 R cement was used according to TS-EN 197/1 standard [53]. The physical and chemical properties of cement were presented in Table 1. Silica fume and quartz based natural sand were used in mixture as aggregate. The maximum grain diameter, specific gravity, water absorption and fineness modulus of the natural sand were 4.70, 2.62, 1% and 2.72%, respectively. All aggregates are utilized conforming to TS 706 EN 12620 Standard [54]. Polycarboxylic ether-based superplasticizer was used in the all mixtures. Technical properties of superplasticizer are shown Table 2.

Red pine needles were used as fiber in the mixture. Material properties of red pine needles are presented in Table 3. Red pine needles were used in 30, 40, 50 mm lengths. Red pine needles were added to the concrete mix at the rates of 0.25%, 0.50%, 0.75% and 1% by volume of mixture. The fibers used in the mixture were not replaced with any materials, they were added directly. Before adding the red pine needles to the concrete, they were soaked in 5% NaOH solution to purify from organic substances [23]. In Fig. 1, untreated and treated forms of red pine needles are shown. The colors of the red pine needles changed into light green for middle and black for edge parts due to the applied chemical treatment. Since red pine needles are a natural material, they do not have a certain diameter. Therefore, the aspect ratio of pine needle fibers varies between 37.5 and 60 depending on the diameter range 0.5–0.8 mm.

2.2. Mix design preparation

The mixture proportions are presented in Table 4. Silica fume, natural sand, cement and fiber used for mixing were placed into the mixer and mixed for 20 s. Then water was added and mixed for 150 s. The samples were placed into the molds in accordance with the standards and cured for 28 days [55,56]. Compressive strength test specimens were placed into cylindrical molds with a diameter of 150 mm and a height of 300 mm. Flexural strength test specimens were placed into 100×100×400 mm molds [57]. For each experimental parameter, 3 experimental specimen groups were prepared. The averages of the obtained results were used.

2.3. Testing methods

2.3.1. Fresh concrete tests

Slump flow and V-funnel tests were applied for fresh concrete properties. The slump flow test was carried out in accordance with the methods determined in the TS EN 12350–8 [58]. The V-funnel test was carried out by following the steps determined in the TS EN 12350–9 [59]. Fresh concrete tests are given in Fig. 2.

2.3.2. Compressive test

The compressive strength of the samples was determined by considering TS EN 12390–3 [60]. The compressive test specimens placed into the mold were tested at the end of 7 and 28 days of curing. As can be seen in Fig. 3, experiments were carried out with the aid of a compressive test machine with a load capacity of 2000 kN. The loading speed was kept constant during the experiments. Cylindrical specimens with dimensions of 150 × 300 mm were used for the experiments. Three samples were prepared for each mixture type. In total, 78 samples were produced for the 7 and 28 day compressive strength tests. The average of the test results of the three samples was accepted as the compressive strength value.

2.3.3. Flexural test

TS EN 12390–5 was followed to determine the flexural strength [61]. 100×100×400 mm prism specimens were tested at the end of the 28-days curing process. Three samples were prepared for each mixture type. 39 specimens were produced for 28-day flexural strength tests. The averages of the flexural strength values obtained from 3 specimens were calculated.

2.3.4. Freezing and thawing test

ASTM C666–03 was followed for freezing thawing testing [62]. In freezing-thawing cycles, the temperature was reduced from 4 °C to − 18 °C and increased from − 18–4 °C. These cycles were repeated 50, 75 and 100 times. The compressive strengths of the specimens were tested at the end of 50, 75 and 100 cycles. The test cabin, which has an operating range between − 40°+ 50 °C, has four stage water level sensor. The heat (temperature) decrease time can be adjusted by the user. The waiting time in the heat (temperature)

Table 2
Technical properties of superplasticizer.

Technical properties of superplasticizer	Value
Colour	Milky brown
Boiling point	95–105 °C
Thermal decomposition	> 720 °C
Density	1.25 g/cm^3
pH value	9.2–12.0
Water solubility	Water-soluble

Table 3
Material properties of red pine needles.

Material properties of pine needles	Values
Amount of inorganic material	0.053
pH	5.92
Holocellulose	81 ± 2
Lignin	13 ± 3
Cellulose	52 ± 5
Tensile strength (MPa)	36.72
Threshold stress (MPa)	36.94
Weibull modulus	5.07

Fig. 1. Red pine needles; (a) Red pine, (b) Untreated red pine needles, (c) treated red pine needles.

Table 4
Mix design proportion.

Specimens	Cement (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Silica Fume (kg/m^3)	W/C	Superplasticizer (%)	Fiber (kg/m^3)
R00-SCUHPC-F0.00	890	160	1050	230	0.18	1.60	0.00
L30-SCUHPC-F0.25	890	160	1050	230	0.18	1.80	5.90
L30-SCUHPC-F0.50	890	160	1050	230	0.18	2.00	11.80
L30-SCUHPC-F0.75	890	160	1050	230	0.18	2.20	17.70
L30-SCUHPC-F1.00	890	160	1050	230	0.18	2.40	23.60
L40-SCUHPC-F0.25	890	160	1050	230	0.18	1.85	7.40
L40-SCUHPC-F0.50	890	160	1050	230	0.18	2.05	14.80
L40-SCUHPC-F0.75	890	160	1050	230	0.18	2.25	22.20
L40-SCUHPC-F1.00	890	160	1050	230	0.18	2.45	29.60
L50-SCUHPC-F0.25	890	160	1050	230	0.18	1.90	9.80
L50-SCUHPC-F0.50	890	160	1050	230	0.18	2.10	19.60
L50-SCUHPC-F0.75	890	160	1050	230	0.18	2.30	29.40
L50-SCUHPC-F1.00	890	160	1050	230	0.18	2.50	39.20

can be adjusted by the user. Waiting time for defrosting can be adjusted by the user. Heating and thawing process is carried out by water filling method. Three samples were prepared for each mixture type. 117 samples were produced for 50, 75 and 100 cycles. The average of the test results of the three samples was accepted as the freeze-thaw test result.

2.3.5. Sulfate attack test

5% Na_2SO_4 solution was prepared for sulfate attack test. The solution was obtained by adding 50 g of Na_2SO_4 into 950 ml of water. Cylindrical specimens with the dimensions of 150 × 300 mm were prepared to be exposed to sulfate attack. The specimens were removed from the mold 24 h after casting. Cured in normal water for 28 days. After 28-days curing, the specimens were dried on their surfaces for one day. The specimens were placed into the sulfate solution tank so that all surfaces were exposed to 5% Na_2SO_4 solution.

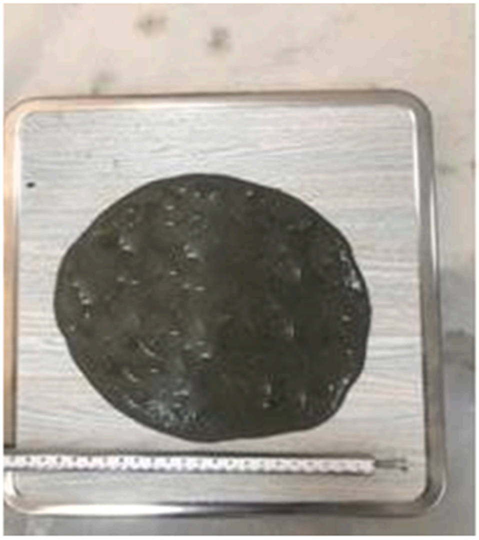

Fig. 2. The slump flow test.

Fig. 3. The compressive strength test.

The compressive strength tests were performed on the specimens exposed to sulfate solution for 90 and 180 days [63]. Three samples were prepared for each mixture type. 78 samples were produced for the 90 and 180 days sulfate attack test. The average of the test results of the three samples was accepted as the sulfate attack test result.

3. Results and discussion

3.1. Fresh concrete properties

The fresh concrete test results of the concrete mixes are given in Table 5 and Fig. 4. Slump-flow test results are presented in Fig. 4 and V-funnel test results are presented in Table 5. SCUHPC fiber inclusion causes a decrease in the flow time of concrete. Flow times in the range of 9–25 s are acceptable values for SCUHPC [59]. Results from all samples are within the limits of UHPC standards. When the values given in Table 1 are examined, it can be seen that the increase in fiber length and increase in fiber amount decrease the flow time. Increase in the fiber amount causes a increase in the viscosity of the mixture as it requires additional mortar to wrap around the

Table 5
The v-funnel test results.

Specimens	V-Funnel (s)
R00-SCUHPC-F0.00	12.1
L30-SCUHPC-F0.25	13.4
L30-SCUHPC-F0.50	14.4
L30-SCUHPC-F0.75	16.7
L30-SCUHPC-F1.00	20.0
L40-SCUHPC-F0.25	14.3
L40-SCUHPC-F0.50	16.6
L40-SCUHPC-F0.75	18.7
L40-SCUHPC-F1.00	20.6
L50-SCUHPC-F0.25	15.8
L50-SCUHPC-F0.50	17.2
L50-SCUHPC-F0.75	18.5
L50-SCUHPC-F1.00	22.3

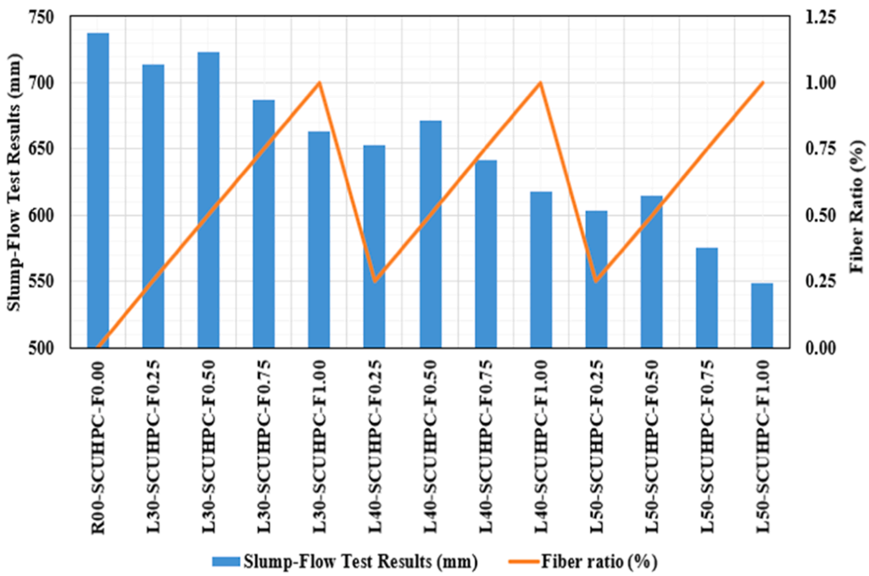

Fig. 4. The slump-flow test results.

fibers. In addition, the increase in the fiber amount increases the agglomeration effect in the concrete. Therefore, the mixtures, since it requires additional mortar to wrap around the fibers In addition, the increase in the fiber amount increases the agglomeration effect in the concrete. Therefore, more amount of water is required to exhibit high flowability [64]. The studies conducted in the past years revealed that increases in fiber aspect ratio and fiber volume can create a fiber network that prevents concrete flow and increases the yield stress of concrete [65]. Increase in the fiber length from 30 mm to 50 mm, also increases the flow time from 13.4 s to 15.8 s. The increase in the usage amount from 0.25% to 1.0% while the fiber length remains the same, increases the flow time from 13.4 s to 20.0 s. Increase in the fiber ratio causes an increase in the air content in the SCUHPC. The increase in air content in the SCUHPC causes a decrease in the flow time [66].

The slump diameter of the reference sample was 738 mm. Despite the same mixing ratios in all samples with fiber adding, results lower than 738 mm were obtained. Increase in the fiber length and fiber amount decreased the slump diameter. The results closest to the reference sample were obtained with the L30-SCUHPC-F0.50 as 723 mm. Slump flow results of 576 mm and 549 mm were obtained for L50-SCUHPC-F0.75 and L50-SCUHPC-F1.00 samples, respectively. These values do not meet the SCUHPC conditions according to TS-EN 12350–8 [58]. According to TS-EN 12350–8, the SCUHPC slump flow should be in the range of 600–750 mm. Fiber adding increases the interlocking and friction between fiber and aggregate, increasing resistance to flow [67]. In addition, increasing the use of fiber increases the viscosity of the SCUHPC and decreases the flowability [68,69].

3.2. Compressive strength test

The compressive test results are presented in Fig. 5. The use of fiber with lengths of 30 and 40 mm, increased the compressive strength. However, the 50 mm length fiber inclusion decreased the compressive strength compared to the reference sample. The compressive strength increased by 12.26%, 15.60%, 14.24% and 13.31% in the samples with fiber content of 0.25%, 0.50%, 0.75%

and 1.00% in the use of 30 mm length fiber, respectively. In the use of 40 mm length fiber, the compressive strength increased by 8.65%, 10.45%, 9.92% and 9.14% in the samples with fiber content of 0.25%, 0.50%, 0.75% and 1.00%, respectively. The failure shape of specimens are given in Fig. 6. The use of fiber creates a bridging effect in the concrete, increasing the compressive strength of the concrete [70]. In other words, fibers increase the crack arresting capacity of concrete [8]. In the use of 50 mm fiber, lower compressive strengths were obtained compared to the reference sample. Compressive strength decreased by 4.26%, 3.57%, 6.00% and 6.75% in the samples with fiber content of 0.25%, 0.50%, 0.75% and 1.00% in the use of 50 mm length fiber, respectively. The use of fiber increases the crack arresting capacity of concrete. However, the increase in fiber length and fiber amount reduces the workability of the concrete and causes voids in the concrete [67]. As a result, the mechanism ended with compressive strength loses. Increasing the amount of fiber up to 0.50% increases the compressive strength of the concrete, while the use of higher amounts of fiber decreases the compressive strength. The findings obtained in previous studies show that if the fiber usage exceeds 0.50%, it does not increase the compressive strength [71–73].

3.3. Flexural strength test

Fiber addition contributes more to flexural strength than its addition to compressive strength test results. The flexural strength of concrete is directly affected by the modulus of elasticity of the fibers and their amount [72]. The flexural strength test results of the samples are given in Fig. 7. An increase in fiber amount up to 0.50% increases flexural strength. Using more than 0.50% fiber slightly reduces the strength, where as, the flexural strength of all samples is higher than the reference sample. The fiber addition reduced the propagation of macrocracks by creating a bridging effect on the cracks [1]. As a result, the flexural strength improved. The increase in fiber length, on the other hand, caused the formation of voids in the concrete with the agglomeration effect. Therefore, the increase in fiber length decreased the flexural strength of concrete. The flexural strength of concrete with 30 mm fiber adding varies between 21.95 and 22.46 MPa, depending on the fiber content. The flexural strength of concrete with 40 mm fiber adding varies between 21.14 and 21.63 MPa, depending on the fiber content. The flexural strength of concrete with 50 mm fiber adding varies between 19.85 and 20.44 MPa, depending on the fiber content.

3.4. Freeze and thaw test

During the freeze-thaw tests, the temperature was lowered from 4 °C to − 18 °C and increased from − 18–4 °C. These cycles were repeated 50, 75 and 100 times. At the end of 50, 75 and 100 cycles, the compressive strength test was conducted for all samples. The F&T test results are presented in Fig. 8. As it is shown in Fig. 8, increase in the number of cycles also increased the strength loss in specimens. This is due to the continuous freezing and melting of the pore water which was already entered the porous structure of the concrete [74], so increase in the number of cycles increased the internal damage amounts [75]. Although the utilization of fiber in the samples had a positive effect up to a certain content, its usage at high rates causes the formation of voids in the concrete. When the F&T test results are examined, it can be seen that the effect of freeze-thaw cycles decreases up to 0.50% fiber inclusion. In addition, the effect increased at higher fiber ratio. It is found that the fiber length also increases the freeze-thaw effect by causing an increase in the

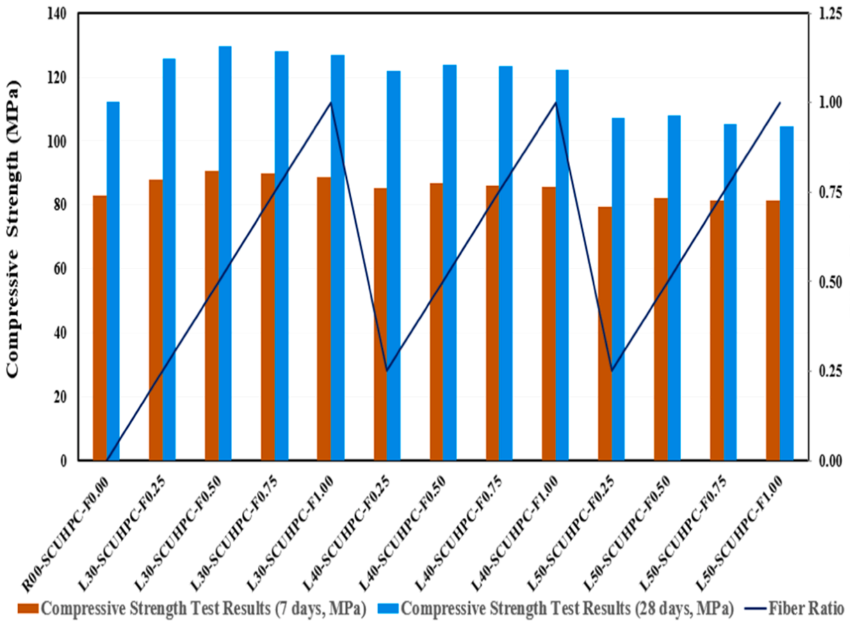

Fig. 5. The compressive strength test results.

Fig. 6. The failure shape of specimens.

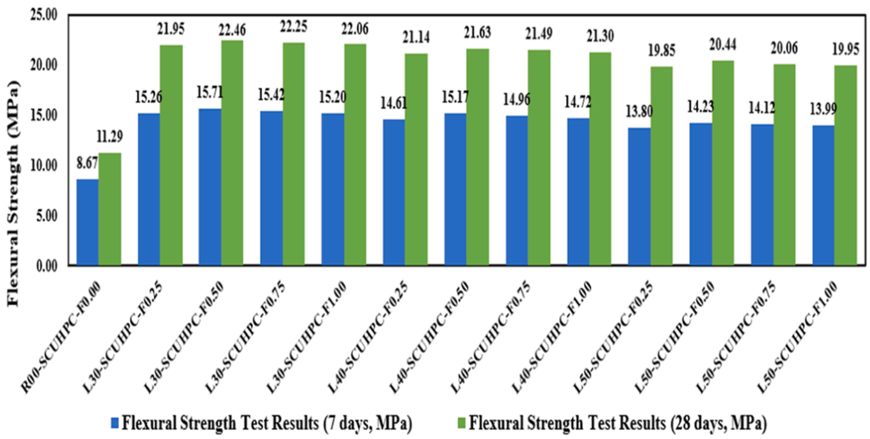

Fig. 7. The flexural strength test results.

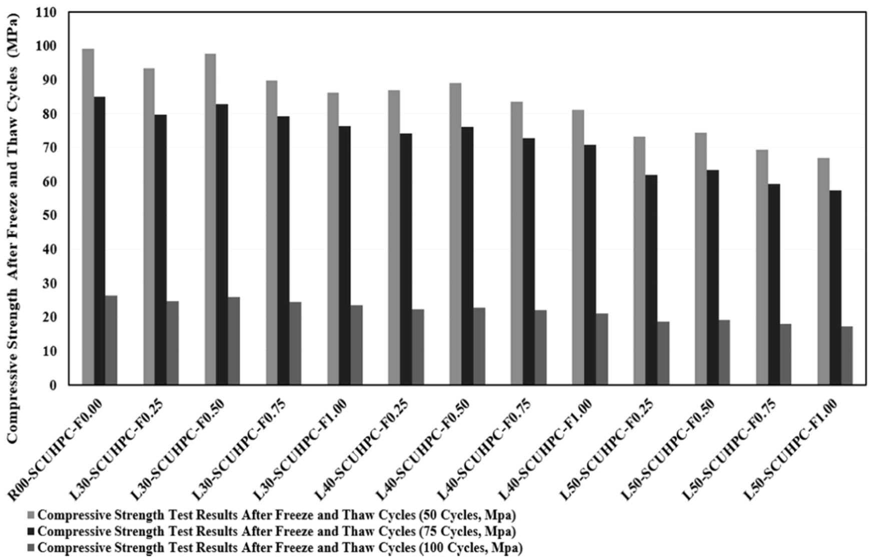

Fig. 8. The compressive strength test results after freeze and thaw cycles.

voids in the concrete. Micro cracks that occur during the cycles can cause faster spreading of damages by lowering the elastic modulus of the concrete.

3.5. Sulfate attack test

Solution containing 5% Na_2SO_4 was prepared for sulfate attack test. Compressive strength test results of samples exposed to sulfate attack are given in Fig. 9. The sulfate ion penetrates into the voids of the concrete and reacts with hydration products such as calcium hydroxide. As a result of the reactions, products such as ettringite and gypsum are formed andthis formation damage the concrete [76]. The formed products fill the voids in the concrete and cause abrasion, expansion and crack formation [77]. In addition, sulfate salts may crystallize in the pores on the surface of concrete and cause physical damages [78,79]. Reference samples was not negatively effected by the sulfate attack due to the its very low void content. The use of fiber in SCC reduces workability and increases viscosity, so a porous concrete structure is formed. The porous structure in concrete increases the losses of compressive strength as a result of sulfate attack. As shown in Fig. 9, the compressive strength losses increase as the increase in the fiber amount and fiber length. Fiber content up to 0.50% provides a positive contribution to the concrete compressive strength losses. If the fiber amount is over 0.50%, it increases the concrete compressive strength losses. Concrete compressive strength losses were obtained as 30.6%, 29.9%, 30.8% and 31.1% for 30 mm fiber length and fiber usage amount of 0.25%, 0.50%, 0.75% and 1.00%, end of 180 days of exposure to sulfate attack, respectively. For 40 mm fiber length and fiber usage amount of 0.25%, 0.50%, 0.75% and 1.00%, concrete compressive strength losses were obtained as 35.1%, 34.5%, 35.3% and 35.9%, respectively, after 180 days of exposure to sulfate attack. Concrete compressive strength losses were obtained as 38.5%, 37.5%, 38.2% and 38.6% for 50 mm fiber length and fiber usage amount 0.25%, 0.50%, 0.75% and 1.00%, after 180 days of exposure to sulfate attack. The reason for this is that 0.50% fiber usage rate reduces the voids in the concrete, and in higher usage, the amount of voids increases by increasing the viscosity in the concrete.

Three samples were prepared for each test. The average of the test results obtained was used. The standard deviation values for each test are presented in Table 6.

4. Conclusion

In this study, the mechanical effects of using red pine needles as a natural fiber for SCUHPC were investigated. Red pine needle was purified from organic matter in alkaline solution. Significant mechanical advantages were obtained for SCUHPC with the use of red pine needles. The results can be drawn as follows:

- The use of 30 mm and 40 mm length fibers was improved the compressive strength and flexural strength of concrete. However, the use of 50 mm length fiber decreased the compressive strength and improved the flexural strength compared to the reference sample. The red pine needles like all other fibers also enhance ductility to concrete. Maximum compressive strength and flexural strength were obtained with L30-SCUHPC-F0.50. The sample with the lowest compressive strength and flexural strength was noticed with L50-SCUHPC-F1.00.
- The slump values closest to the reference sample were obtained with the use of − 0.50% and 30 mm length fiber. In other samples, the workability decreased with the effect of increasing viscosity and agglomeration effect. The maximum reduction in slump

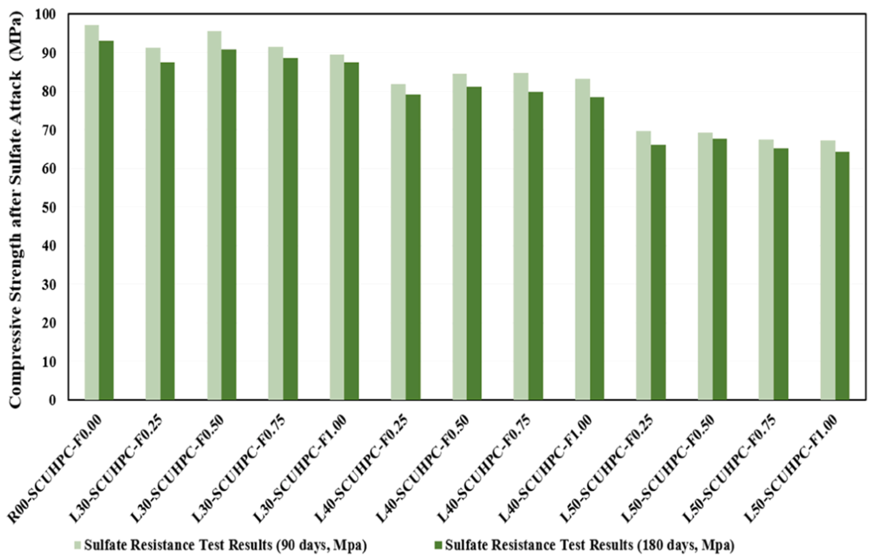

Fig. 9. The compressive strength test results after sulfate attack.

Table 6
The standard deviation values for each test.

Samples	Standard Deviations								
	Comp. Strength (7 days)	Comp. Strength (28 days)	Flex. Strength (7 days)	Flex. Strength (28 days)	Freeze and Thaw (50 cycles)	Freeze and Thaw (75 cycles)	Freeze and Thaw (100 cycles)	Sulfate Resist. (90 days)	Sulfate Resist. (180 days)
R00-SCUHPC-F0.00	1.948	2.623	0.347	0.459	2.517	2.154	1.841	2.484	1.917
L30-SCUHPC-F0.25	2.157	2.967	0.792	1.075	2.624	2.245	1.976	2.547	2.047
L30-SCUHPC-F0.50	2.328	2.786	0.719	1.192	2.656	2.293	2.149	2.576	2.145
L30-SCUHPC-F0.75	2.364	2.641	0.891	1.118	2.578	2.184	2.058	2.374	2.204
L30-SCUHPC-F1.00	2.249	2.543	0.731	1.174	2.492	1.946	2.089	2.481	1.978
L40-SCUHPC-F0.25	2.078	2.581	0.876	1.092	2.541	1.875	1.791	2.393	1.846
L40-SCUHPC-F0.50	2.247	2.462	0.827	1.081	2.593	2.017	1.815	2.341	2.071
L40-SCUHPC-F0.75	1.984	2.617	0.751	1.039	2.485	1.879	1.917	2.392	1.914
L40-SCUHPC-F1.00	1.913	2.384	0.634	1.054	2.392	1.924	1.713	2.427	1.876
L50-SCUHPC-F0.25	2.075	2.476	0.745	0.957	2.418	1.974	1.872	2.473	1.761
L50-SCUHPC-F0.50	1.892	2.317	0.692	1.048	2.351	1.862	1.691	2.436	1.893
L50-SCUHPC-F0.75	1.967	2.384	0.613	0.969	2.397	1.875	1.768	2.382	1.841
L50-SCUHPC-F1.00	1.846	2.428	0.48	0.914	2.319	1.813	1.741	2.357	1.792

diameter was noticed in sample L50-SCUHPC-F1.00. The maximum slump-flow diameter and minimum slump time were obtained in the L30-SCUHPC-F0.50 sample.

- With the use of 0.50% fiber in 30 mm length, freeze-thaw and sulfate attack effects were observed closest to the reference sample. Negative effects were observed with increasing amounts and lengths of fiber. As a result, 30 mm length and 0.50% usage amount should be preferred for use in places with high temperature differences or exposed to sulfate effect.
- The outcomes of this study can be the basis for the optimization of SCUHPCs.

Declaration of Competing Interest

The author declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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