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Utilization of Steel Micro-fiber and Carbon Nanotubes in Self-compacting Lightweight Concrete

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ABSTRACT

In this research, the engineering characteristics of self-compacting lightweight concrete (SCLWC) containing carbon nanotubes and steel micro-fiber were evaluated. The variables included the amount of carbon nanotubes (0, 0.02, 0.04, and 0.06% by weight of cement) and steel micro-fiber (0, 0.5, and 1% by volume). Lightweight expanded clay aggregate was used as lightweight aggregates. The experimental tests were self-compacting tests, compressive, splitting tensile, and flexural strengths, ultrasonic pulse velocity, electrical resistivity, water penetration depth, and scanning electron microscope. Adding 0.02 to 0.06 percent of carbon nanotubes to SCLWC reinforced with steel micro-fiber increases the compressive strength by about 33 to 64 percent. The use of 0.06% carbon nanotubes and 1% steel micro-fiber increased the splitting tensile strength by 36%. The use of carbon nanotubes and steel micro-fiber has the effect of influencing the filling of empty spaces and reducing concrete porosity. This can be attributed to the growing process of cement paste hydration and the filling of pores and capillary pores with the products of cement reactions, resulting in concrete compaction. Adding 0.02% carbon nanotubes to SCLWC samples containing 0.5% and 1% steel micro fibers increased the 28-day compressive strength by 36%, 34% and 33%, respectively.

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1. INTRODUCTION

The use of old materials and traditional construction methods no longer meets the desired speed and design needs. Therefore, the use of new and effective materials along with new techniques in construction is inevitable [1-3]. Researchers are trying to produce desirable structures by reducing the weight of concrete structures, easing their construction, using high-strength materials, and increasing durability in destructive environments. Lightweight concrete (LWC) has attracted the attention of researchers as a suitable option for building concrete structures [4-7]. Fiber concrete with high strength has many structural applications [8]. The strength of fiber concrete under static and dynamic loads is increased and the propagation of cracks and crushing is reduced [9, 10]. In recent years, extensive research has been done for the advancement and innovation in the use of micron fibers and nanoparticles to improve the mechanical behavior of cement and concrete compounds [11, 12]. According to these micron-scale research studies, it is very important to pay attention to nanoparticles with the help of knowledge and nanotechnology and study their effects on concrete properties.

Afzali and Mazloum [13] investigated the fresh and hardened properties of LWC-containing nano-silica. The results showed that the combined use of silica fume and nano-silica had a more effective role in improving the characteristics of LWC.

Abd Elrahman et al. [14] investigated the effect of silica nanoparticles on the characteristics, durability, and microstructure of LWC. Silica nanoparticles modified the structure of fine pores and thus improved the transfer characteristics. Wu et al. [15] investigated LWC reinforced with steel and carbon fibers. The water-to-cement ratio and the characteristics of the aggregates can

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have a role in influencing the results. Badogiannis et al. [16] evaluated LWC reinforced with steel and polypropylene fibers. For this purpose, pumice was used as a filler. The use of fibers improves the mechanical properties of LWC and significantly increases the compressive and flexural strengths. It was also shown that the use of fibers improves the cracking resistance of concrete. Yeganeh et al. [17] investigated the characteristics of fiber LWC. For this purpose, three types of high-density polyethylene fibers, rubber crumbs, and polyvinyl alcohol were used. The fibers decreased the crack width in the failure stage. Lan et al. [18] investigated carbon nanotube-modified concrete. They showed that carbon nanotubes improved the characteristics of concrete by improving crack resistance. Liu et al. [19] evaluated the effect of carbon nanotubes on reactive powder concrete performance in a sulfate dry-wet cycling environment. Carbon nanotubes limited concrete cracks.

Considering the advantages mentioned about the use of steel fibers, and carbon nanotubes, in the present study, self-compacting lightweight concrete (SCLWC) containing different volume ratios of steel micro-fiber and carbon nanotubes was investigated. Finally, an optimal combination of the mentioned additives was determined.

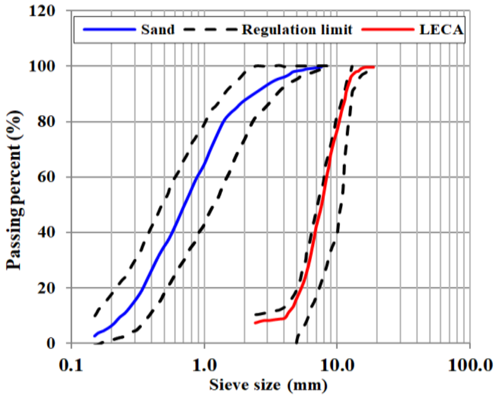


Figure 1. The grading curve of the sand and LECA


(a) (b)

Figure 2. Material used (a) LECA (b) Carbon nanotubes

TABLE 1. The properties of carbon nanotubes

Characteristic	Quantity
External diameter (nm)	20-30
Length (mm)	10
Ash percentage (%)	0.2
Purity (%)	95
Specific surface (m^2/gr)	250-280
Amorphous carbon (%)	3

2. MATERIAL CHARACTERISTICS AND METHODS

2. 1. Material The materials used in the present laboratory study included sand, lightweight expanded clay aggregate (LECA), cement, water, superplasticizer, carbon nanotubes, and steel micro-fiber. The sand used was natural sand. According to ASTM-C33 [20], the grading curve of the used sand is illustrated in Figure 1. Natural sands are river sands that are extracted from riverbeds. The characteristics of these sands are their rounded corners. The sand was obtained from the Joben Rudbar mine located in Gilan province, Iran. This sand was free of harmful particles and dust. The specific gravity, fineness Modulus, and water absorption of the sand used were 2627 kg/m^3, 2.89 and 3%, respectively.

The specific weight of the used LECA is 660 kg/m^3 (Figure 2(a)). The LECA granulation curve is presented in Figure 1. The LECA granulation curve is within the permissible range of ASTMC33 [21] standard.

The specifications of the carbon nanotubes are listed in Table 1. They were prepared by the Iranian oil industry research institute and have a specific surface area of 3200 g/cm^3 and a density of 15.3 g/cm^3. Carbon nanotubes are cylinders of carbon whose wall diameter is about nanometers. These tubes are seamless and made of one or more carbon layers. They are available in single-walled (SWCNT) and multi-walled (MWCNT) forms. In these tubes, carbon atoms with a hexagonal and hollow ring structure were placed together, giving a cylindrical shape to the structure (Figure 2(b)).

The fibers used in this research were of the straight type and had micro dimensions (diameter 0.15 and length 14 mm). (Table 2). Despite the advantages of microfibers, some considerations should be made to distribute the fibers uniformly prevent separation or the phenomenon of lumping and create an effective mixture for concreting, densification, and polishing of concrete, sieving is one of these methods.

The pH of the water is about 7.5. The Polycarboxylate superplasticizer was used in order to achieve the desired workability.

2. 2. Experimental Methods The tests related to fresh concrete according to EFNAC [21] method included V-funnel, T50, L-box, and slump flow tests.

TABLE 2. The properties of steel micro-fiber

Characteristic	**Quantity**
Length (mm)	20-30
Diameter (mm)	10
Tensile strength (MPa)	0.2

Self-compacting concrete measurement parameters were used to measure the workability of self-compacting concrete containing carbon nanotubes and steel micro-fiber.

The compressive strength (CSt) test was performed in accordance with ASTM C39 [22]. The tensile strength of concrete was determined using the split tensile strength (SPTSt) test according to ASTM C496 [23].

The ultrasonic pulse velocity was measured using a non-destructive ultrasonic device according to ASTM C597 [24]. This test is proposed based on the theory of ultrasound transmission inside the material, which is generally used to obtain information about concrete porosity [25, 26].

Electrical resistivity (ER) is considered an indicator of communication between holes. This index determines the resistance of concrete against the penetration of liquid or gas through the concrete surface which is in contact with the outside environment. This parameter is considered one of the most key parameters related to the durability of concrete. Electrical resistance is one of the intrinsic properties of materials, which mainly depends on the nature and topography of the cavity structure, humidity conditions, temperature, and concentration of dissolved ions in the environment [27-29]. In order to perform this test, an electrical resistance measuring device with a variable frequency of 10 to 10000 Hz was used. ER was calculated using Equation (1).

$$\rho = \frac{R.A}{L} \tag{1}$$

In this regard, ρ is specific ER, R is Electrical resistance, A is the surface area of the concrete in square meters and L is the distance between the positive and negative poles.

Estimating the probability of corrosion of reinforcements buried in concrete based on ER is presented in Table 3.

The water penetration depth (WPD) in the SCLWC samples was determined according to DIN 1048-5. According to this test underwater pressure at a certain time, the WPD in concrete is determined. The cubic samples were taken out of the water pool for 28 days and kept inside the oven for 20 hours at a temperature of 111°C to dry completely. For one day (24 hours), the samples were placed in the device for determining the WPD, and under a pressure equal to 10 bars after the test, they were split in half using a cutting device and divided into two halves, and the WPD was measured [30].

2. 3. Mixed Design

The specifications of the mixing plant and the amounts of each of the consumables are presented in Table 4. The desired mixing design was

TABLE 3. Estimating the probability of corrosion of reinforcements buried in concrete based on ER [31, 32]

ER (kΩ-m)	**Possibility of corrosion**
50<	Very high
50-100	High
100-200	Moderate
200>	Very low

TABLE 4. Mixture design

Mix code	**W/B**	**Cement (kg/m^3)**	**CN**	**SMF**	**W**	**Sand**	**LECA**	**SP**
CNTs0SF0	0.4	405	0	0	180	950	393	1.15
CNTs0SF0.5	0.4	405	0	0.5	180	950	393	1.20
CNTs0SF1	0.4	405	0	1	180	950	393	1.25
CNTs0.02SF0	0.4	396.9	8.1	0	180	950	393	1.17
CNTs0.02SF0.5	0.4	396.9	8.1	0.5	180	950	393	1.23
CNTs0.02SF1	0.4	396.9	8.1	1	180	950	393	1.30
CNTs0.04SF0	0.4	388.8	16.2	0	180	950	393	1.21
CNTs0.04SF0.5	0.4	388.8	16.2	0.5	180	950	393	1.27
CNTs0.04SF1	0.4	388.8	16.2	1	180	950	393	1.35
CNTs0.06SF0	0.4	380.7	24.3	0	180	950	393	1.26
CNTs0.06SF0.5	0.4	380.7	24.3	0.5	180	950	393	1.34
CNTs0.06SF1	0.4	380.7	24.3	1	180	950	393	1.40

W: Water B: Binder CN: Carbon nanotubes MSF: Steel micro-fiber
LECA: Light Expanded Clay Aggregate SP: Superplasticizer

obtained using past experimental studies and by trial and error in accordance with ACI [30]. The variables include carbon nanoparticles (0, 0.5, 1, 1.5, and 2% by weight of cement) and steel micro-fiber (0, 0.5, and 1% by volume of concrete), respectively. After making and molding, the samples were kept in the mold for 24 hours. Then, it was taken out of the mold and subjected to moisture treatment until the tests were performed.

3. EXPERIMENTAL RESULTS

3. 1. Examining the Properties of Fresh Concrete

The concrete should be workable but not excessively bleeding. Concrete bleeding is the movement of water toward the surface of freshly poured concrete, which is caused by the settling of solid materials including cement, sand, and gravel inside the concrete mass. The settling of solid particles is the result of the sum of the effects of shaking and the weight of the particles [33]. Figure 3 shows the values of concrete slump flow in seconds and the formation time of 500 mm diameter in seconds (T50). The slump flow of the control sample was found to be 782 mm. The use of 0.5% and 1% steel micro-fiber caused the slump flow to be 768 and 756 mm, respectively; that is, the addition of 0.5% and 1% steel micro-fiber reduced the slump flow of LWC by about 1.8% and 3.3%.

Also, the slump flow of LWC samples without fibers and containing 0.02, 0.04, and 0.06 % of carbon nanotubes are 751, 752, and 691 mm, respectively. Adding 0.02, 0.04 and 0.06 % of carbon nanotubes reduced the slump flow by 4, 3.8, and 11.6 %, respectively. Also, the combined use of carbon nanotubes and steel micro-fiber reduced the slump flow. For example, the combined use of 0.06% of carbon nanotubes and 1% of steel micro-fiber reduced the slump flow of SCLWC by about 15%.

The slump flow range is by the EFNARC standard in the range of 650 to 800 mm. All SCLWC samples are in this range. Although the addition of steel micro-fiber and carbon nanotubes reduces the slump flow of LWC, it is possible to overcome this problem by using a superplasticizer and achieve concrete with permissible slump flow. Of course, excessive use of polycarboxylate-based superplasticizers leads to an increase in concrete aeration and affects the mechanical and reliability characteristics of concrete.

By increasing the percentage of carbon nanotubes, the amount of slump current also increases. The reason for this can be attributed to the roughness of the mixture and its tendency to flow. Concretes with carbon nanotubes and steel micro-fiber have the lowest amount of slump flow.

In Figure 3 in addition to the slump current, T50 values are also compared with each other. The use of both types of proposed materials has increased the T50 time and reduced the fluidity of concrete. So that the T50 time of the control sample is equal to 1.4 seconds and the T50 time of the sample containing 0.06% carbon nanotubes and 0.5% steel micro-fiber is 4.9 seconds. Also, the allowed range introduced for T50 is between 2 and 5 seconds, and all the samples made are in this range.

Figure 4 compares the concrete discharge time from the V-shaped funnel and the blockage ratio in the L-box test. The results of the V-funnel and L-box tests are in agreement with the slump flow and T50 tests; because in these two experiments, the addition of steel micro-fiber and carbon nanotubes affected the workability of concrete and led to a decrease in the flowability of LWC samples.

According to the EFNARC recommendation, the time for concrete discharge from the V-funnel is between 6 and 12 seconds. As it is known, the time related to the emptying of the witness concrete from the V-shaped funnel is equal to 2.8 seconds. Meanwhile, the time for emptying the concrete containing 0.06% carbon nanotubes and 1% steel micro-fiber is equal to 10.9 seconds. On the other hand, the diagram related to the blocking ratio of the L box test in Figure 4 is descending.

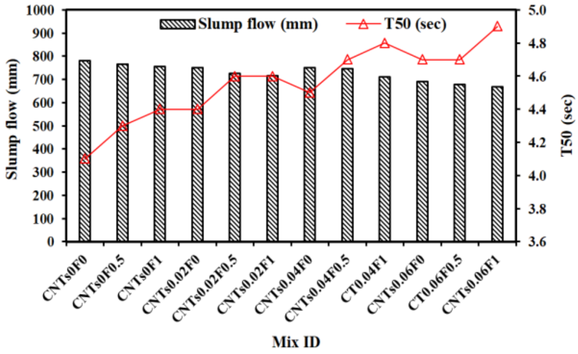


Figure 3. Comparison of slump flow values and T50 times of SCLWC samples

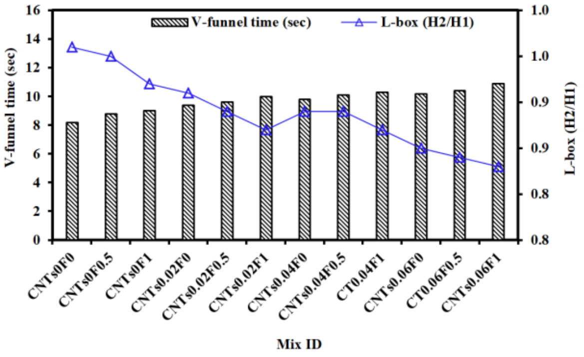


Figure 4. Comparison of the concrete discharge time from the V funnel and the blockage ratio in the L box test

Steel micro-fiber reduces the flow of concrete by creating friction in LWCs containing LECA and carbon nanotubes. To overcome this problem, you can use super lubricant within the allowed range. The allowed occlusion ratio introduced by EFNARC is between 0.8 and 1. All the samples made are in this range.

3. 2. Mechanical Characteristics

3. 2. 1. CSt Figures 5 and 6 compare the CSt of 7 and 28 days of SCLWC samples, respectively. The use of carbon nanotubes has a role in increasing the CSt of SCLWC samples with and without steel micro-fibers. In SCLWC samples without steel micro-fibers, the addition of 0.02, 0.04, and 0.06% of carbon nanotubes has increased the 7-day CSt by 35, 57, and 62%, respectively. In SCLWC samples containing 0.5% of steel micro-fibers, the addition of 0.02%, 0.04%, and 0.06% of carbon nanotubes increased the 7-day CSt by 34%, 58%, and 64%, respectively. Also, in SCLWC samples containing 1% steel micro-fibers, the addition of 0.02%, 0.04%, and 0.06% carbon nanotubes has increased the 7-day CSt by 32%, 53%, and 62%, respectively. Therefore, it can be stated that the addition of 0.02 to 0.06 carbon nanotubes to SCLWC reinforced with steel micro-fibers increases the 7-day CSt by about 32 to 64%, depending on the amount of microfibers.

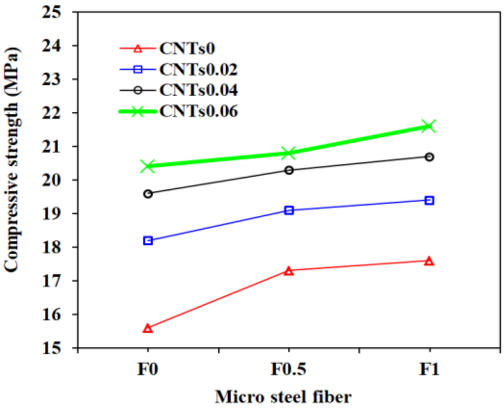


Figure 5. Comparison of 7-day CSt of SCLWC samples

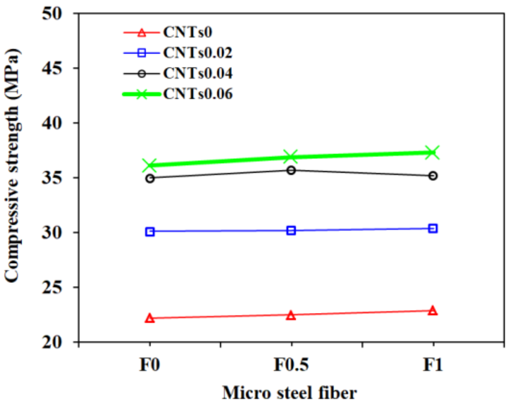


Figure 6. Comparing the 28-day CSt of SCLWC

Figure 4 compares the 28-day CSt of SCLWC samples. The addition of carbon nanotubes to all samples has led to an increase in the 28-day CSt.

The 28-day CSt of SCLWC samples containing 0, 0.5, and 1% of steel micro-fibers, in which without carbon nanotubes were 22.2, 22.5, and 22.9 MPa, respectively. The addition of 0.02 to SCLWC samples containing 0, 0.5, and 1% steel microfibers has increased the 28-day CSt by 36, 34, and 33%, respectively. Adding 0.04 to SCLWC samples containing 0, 0.5, and 1% steel microfibers increased the 28-day CSt by 58, 59, and 54%, respectively. Also, the addition of 0.06 to SCLWC samples containing 0, 0.5, and 1% steel microfibers increased the 28-day CSt by 63, 64, and 63%, respectively.

3. 2. 2. SPTSt The addition of 0.02, 0.04 and 0.06% of carbon nanotubes increased the SPTSt by 13, 20 and 27%, respectively (Figure 7). Also, the addition of 0.5% and 1% steel micro-fibers increased the SPTSt by 15% and 19%. The combined use of 0.06% of carbon nanotubes and 1% of steel fibers increased the SPTSt by 36%. Therefore, it can be stated that the use of carbon nanotubes and steel micro-fibers together has a more effective role compared to the single use of each of them.

ACI 318-99 [34] and EN 1992-1 [35] regulations introduce a range for tensile strength based on cylindrical CSt. These ranges are presented in Figure 8.

Since these relationships are between cylindrical CSt and tensile strength, and the strength results of the upcoming study were obtained on cubic samples based on the test results, first, the CSt results obtained from the cubic sample were converted to cylindrical CSt. Figure 8 shows the relationship between the tensile and CSts values of the upcoming study and the aforementioned regulations, as well as the studies of Coquillat [36] and Berg [37]. The results of the present study are very close to the experimental curves introduced by ACI318-99 [34].

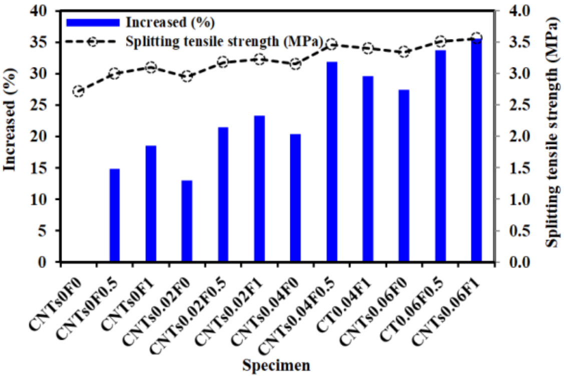


Figure 7. SPTSt and percentage increase

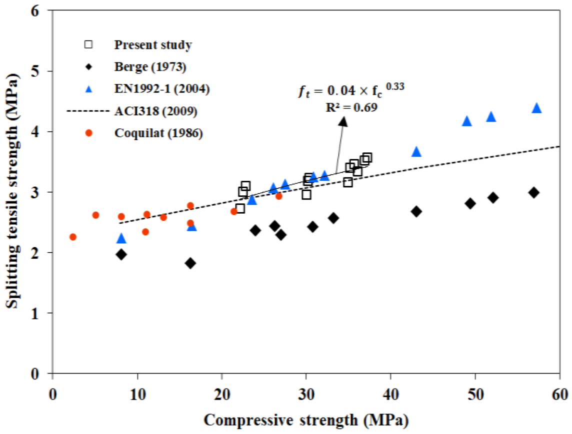


Figure 8. The relationship between the CSt and SPTSt of SCLWC containing steel micro-fibers and carbon nanotubes

Based on Figure 8, Equation (3) presented.

$$f_t = 0.4 \times (f_c)^{0.33} \quad (3)$$

3. 2. 3. Ultrasonic Pulse Velocity

This test can be done at a low cost and quickly, which confirms its suitability from every point of view for evaluation. In this research, the trend of changes in the ultrasonic pulse velocity was investigated in different designs at the age of 28 days for 10×10×10 cm samples. In Figure 9 the results of ultrasonic pulse velocity against the CSt of cubic concrete samples are presented. Whitehurst [37] classified concrete into five categories based on the speed of ultrasonic waves: excellent (greater than 4500 m/s), good (3500 to 4500 m/s), questionable (3000 to 3500 m/s), poor (2000 to 3000 m/s) and very weak (less than 2000 m/s). According to this classification, all designs are in the "good" range. More porosity results in a lower pulse velocity.

The use of carbon nanotubes and steel micro-fibers together leads to an improvement in concrete density. The carbon nanotubes fill the fine pores of the cement, and the steel micro-fibers prevent the development of micro cracks. The rate of increase in ultrasonic pulse velocity was observed to be slower than the compressive resistance. The steel micro-fibers increased the ultrasonic pulse velocity.

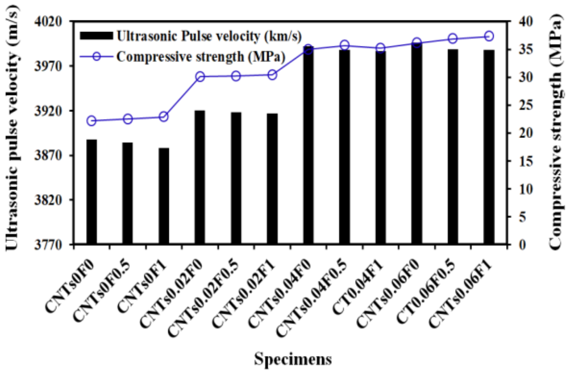


Figure 9. CSt and ultrasonic pulse velocity

3. 2. 4. Microstructure of the Concrete Samples

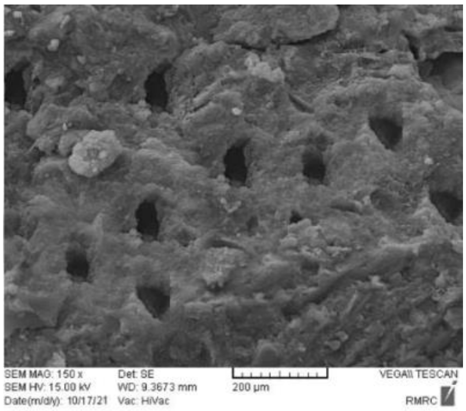
Four samples were selected to represent the manufactured samples and their SEM images were prepared (Figure 10). These samples include CNTs0F0, CNTs0F1, CNTs0.04F0 and CNTs0.04F1, respectively.

The purpose of choosing these SCLWC samples was to evaluate the effect of steel micro-fibers and carbon nanotubes individually and in combination on the microstructure of SCLWC. The use of carbon nanotubes in combination with steel micro-fibers is effective in making SCCLWC contain LECA. The steel micro-fibers prevent the crack from spreading and the carbon nanotubes fill the holes created by the microfibers. Also, carbon nanotubes lead to improvements in the mechanical properties and durability of concrete by filling the very small holes in the cement.

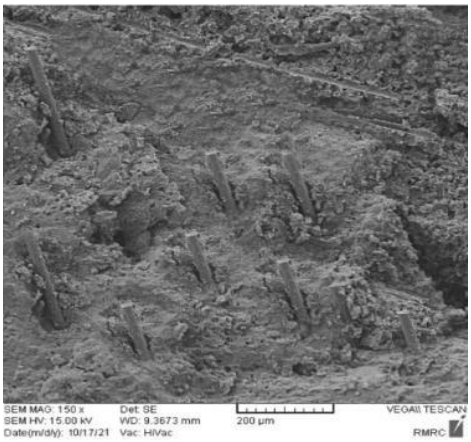
3. 3. Durability Characteristics

3. 3. 1. ER

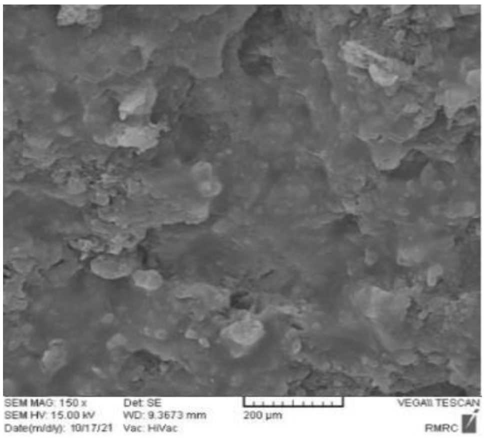
In Figure 11, the ER of the SCLWC samples at 90 days of age is compared with each other.



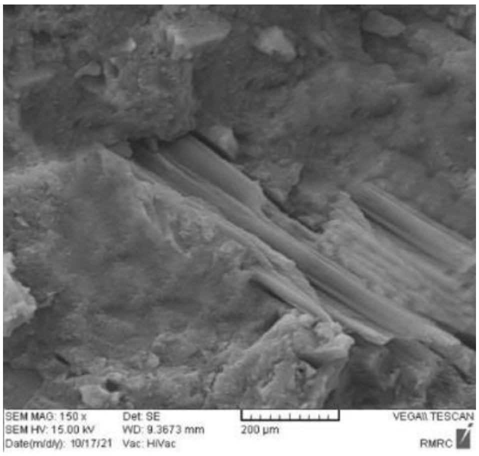
CNTs0F0



CNTs0F1



CNTs0.04F0



CNTs0.04F1

Figure 10. Microstructure examination of concrete samples

The higher the electrical resistance, the more durable and desirable concrete will be, and its corrosion will be less. Song and Saraswathy [29] and Alki and Selevold [30] divide concrete into four categories in terms of corrosion probability. Adding carbon nanotubes to SCLWC samples containing steel micro-fibers has been effective and has increased the electrical resistance by 87-173% compared to the control sample. As a result, concrete corrosion is reduced. In other words, the resistance of concrete against corrosion increases. The electrical resistance of all samples with fibers is lower than the control sample. This issue is due to the fact that the presence of fibers in concrete increases the air content of the concrete, and in this way, the electrical resistance decreases in samples reinforced with fibers.

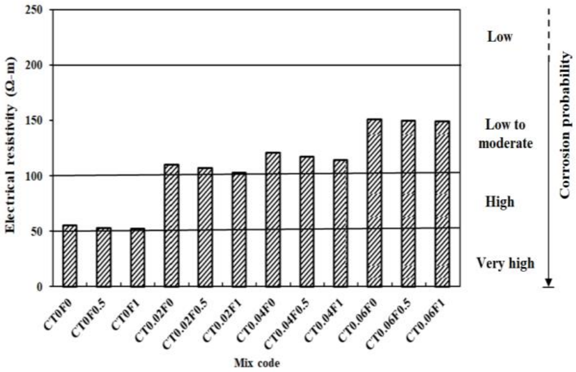


Figure 11. ER of samples in different states

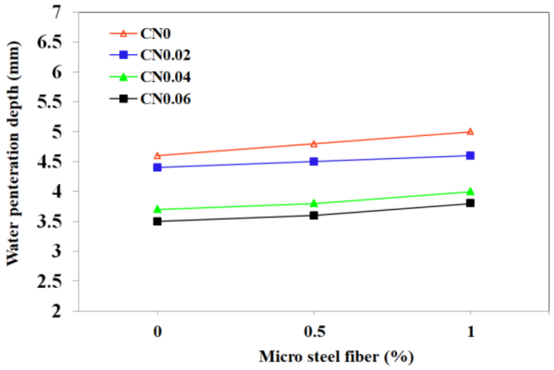


Figure 12. The WPD of samples in different modes

3. 3. 2. Water Penetration Depth (WPD) The addition of carbon nanotubes to SCLWC samples containing steel micro-fibers significantly reduced the WPD (Figure 12). Adding 0.02, 0.04 and 0.06 percent of carbon nanotubes to samples without steel micro-fibers reduced the WPD by 4, 19 and 24 percent, respectively. Adding 0.02%, 0.04% and 0.06% of carbon nanotubes to the SCLWC samples containing 0.5% steel micro-fibers reduced the WPD by 6%, 21% and 25%, respectively. Also, adding 0.02, 0.04, and 0.06 percent of carbon nanotubes to the SCLWC samples containing 1 percent of steel micro-fibers reduced the WPD by 8, 20, and 24 percent, respectively. The powder effect and pozzolanic reaction speed of the used carbon nanotubes are among the reasons for the reduction of water infiltration inside the investigated SCLWC samples.

4. CONCLUSIONS

In this study, the rheological, mechanical, durability, and microstructure characteristics of concretes containing steel micro-fibers and carbon nanotubes by performing slump flow, T50, L box, and V funnel tests, CSt, SPTSt strength, speed of ultrasonic waves, electrical resistance, water absorption, determination of water penetration depth and microscopic photography were evaluated.

- Although the addition of steel micro-fibers and carbon nanotubes reduces the slump flow of LWC; it is possible to overcome this problem by using superplasticizer and achieve concrete with permissible slump flow. Of course, excessive use of polycarboxylate-based superplasticizers leads to an increase in concrete aeration and affects the mechanical and reliability characteristics of concrete.

- By increasing the amount of carbon nanotubes, the amount of slump current increases. The reason for this can be attributed to the roughness of the mixture and its lower tendency to flow. Concretes with carbon nanotubes and steel micro-fibers have the lowest amount of slump flow.
- The addition of steel micro-fibers and carbon nanotubes affected the workability of concrete and led to a decrease in the flowability of SCLWC samples.
- Steel micro-fibers reduced the flow of concrete by creating friction in LWC containing LECA and carbon nanotubes. To overcome this problem, a superplasticizer within the allowed range can be used.
- Adding carbon nanotubes from 0.02 to 0.06 to LWC reinforced with steel micro-fibers increases the 7-day CSt by about 32 to 64%, depending on the amount of steel microfibers.
- Adding 0.02% carbon nanotubes to SCLWC samples containing 0.5% and 1% steel microfibers has increased the 28-day CSt by 36%, 34%, and 33%, respectively.
- Adding 0.04 percent of carbon nanotubes to SCLWC samples containing 0, 0.5, and 1 percent of steel micro fibers has increased the 28-day CSt by 58, 59, and 54 percent, respectively.
- The addition of 0.06 percent of carbon nanotubes to SCLWC samples containing 0, 0.5, and 1 percent of steel micro-fibers has increased the 28-day CSt by 63, 64, and 63 percent, respectively.
- The addition of 0.02, 0.04, and 0.06 carbon nanotubes has increased the SPTSt by 13, 20, and 27%, respectively. Also, the addition of 0.5% and 1% steel micro-fibers has increased the SPTSt by 15% and 19%, respectively. The combined use of 0.06% of carbon nanotubes and 1% of steel fibers has increased the SPTSt by 36%. Therefore, it can be stated that the combined use of carbon nanotubes and steel micro-fibers has a more effective role compared to the single use of each of them.
- The combined use of carbon nanotubes and steel micro-fibers has the effect of influencing the filling of empty spaces and reducing concrete porosity. This can be attributed to the growing process of cement paste hydration and the filling of pores and capillary pores with the products of cement reactions, resulting in concrete compaction.
- The addition of carbon nanotubes to the SCLWC samples with and without steel micro-fibers causes a great increase in electrical resistance. The resistance of concrete against corrosion increases. The electrical resistance of all SCLWC samples with fibers is lower than the control sample. The resistance decreases due to the presence of metal particles.
- Adding 0.02, 0.04, and 0.06 percent of carbon nanotubes to SCLWC samples without steel micro-fibers reduced the WPD by 4, 19, and 24 percent, respectively. Adding 0.02%, 0.04%, and 0.06% of carbon nanotubes to the SCLWC samples containing 0.5% steel micro-fibers has reduced the water penetration depth by 6%, 21%, and 25%, respectively. Also, adding 0.02, 0.04, and 0.06 percent of carbon nanotubes to the samples containing 1 percent of steel micro-fibers has reduced the depth of water penetration by 8, 20, and 24 percent, respectively.

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Persian Abstract

چکیده

در این تحقیق، ویژگی‌های مهندسی بتن سبک خود متراکم (SCLWC)حاوی نانولوله‌های کربنی و میکروالیاف فولادی مورد ارزیابی قرار گرفت. متغیرها شامل مقدار نانولوله کربنی (٠، ٠.٠٢، ٠.٠٤ و ٠.٠٦ درصد وزنی سیمان) و میکروالیاف فولادی (٠، ٠.٥ و ١ درصد حجمی) بودند. از سنگدانه های رس منبسط شده سبک وزن به عنوان سنگدانه های سبک استفاده شد. آزمون های خود تراکم، مقاومت فشاری، شکاف کششی و خمشی، سرعت پالس اولتراسونیک، مقاومت الکتریکی، عمق نفوذ آب و میکروسکوپ الکترونی روبشی بودند. افزودن ٠.٠٢ تا ٠.٠٦ درصد نانولوله های کربنی به SCLWC تقویت شده با میکروالیاف فولادی، مقاومت فشاری را حدود ٣٣ تا ٦٤ درصد افزایش می دهد. استفاده از نانولوله های کربنی ٠.٠٦ درصد و میکروالیاف فولادی ١ درصد استحکام کششی شکافتگی را تا ٣٦ درصد افزایش داد. استفاده از نانولوله های کربنی و میکروالیاف فولادی بر پر شدن فضاهای خالی و کاهش تخلخل بتن تأثیر می گذارد. این را می توان به روند رو به رشد هیدراتاسیون خمیر سیمان و پر شدن منافذ و مویرگی با محصولات واکنش سیمان و در نتیجه تراکم بتن نسبت داد. افزودن ٠.٠٢ درصد نانولوله های کربنی به نمونه های SCLWC حاوی ٠.٥ درصد و ١ درصد الیاف میکرو فولاد، مقاومت فشاری ٢٨ روزه را به ترتیب ٣٦، ٣٤ و ٣٣ درصد افزایش داد.