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Rheological and Mechanical Properties of Light Weight Self-Compacting Concrete Containing Sirjan Iron Mine Waste

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Abstract
Recycling is a logical option for materials that are not suitable for composting. One of these materials is iron mines waste that, according to their compounds, can be used as a substitute part of cement in concrete. For this aim, rheological and mechanical properties and durability of light weight self-compacting concrete (LWSCC) containing Sirjan iron mine waste (SIMW) as partial substitute of cement is presented in this paper. For this purpose, part of cement was replaced with 5, 10, 15 and 20 wt% SIMW. It's founded that the addition of SIMW as substitute part of cement decrease flowability, viscosity and filling ability of LWSCCs but all of the mixtures were in the allowable range accordance EFNARC (2005). Replacement of 5 wt% and 10 wt% of cement with SIMW resulted 8.6% and 20% increase in compressive strength with respect to control mixture, respectively. By increasing percent of SIMW compressive strength decreased. This trend was observed for tensile and flexural strength and water penetrability of LWSCCs.

Keywords: iron mine waste, light weight concrete, self-compacting concrete, mechanical properties

Introduction

With every mineral activity, there are a lot of waste that, due to their inadequate use, usually stored in waste dams near the mines, and in most cases they are not used extensively. The volume of solid waste generated, including tailings from mineral processing activities, is one of the main pollution concerns in the mining industry. Therefore, ways of utilizing mine waste need to be found (Yellishetty et al., 2008). The use of mine waste as a construction material for embankments of roadways, railways, rivers and dams instead of using natural soil has increased in the last 20 years. Mine waste is also widely used in land reclamation and backfilling of opencast quarries (Skarzynska, 1995b). Reuse of industrial solid waste as a partial replacement of aggregate and cement in concrete was studied by many researchers. The use of steel slag as an aggregate for concrete mixes was investigated by Akinmusuru (1991) ; based on the short-term results and the crushing strengths, ''slagcrete'' appeared to have potential in the construction industry. The possibility of using metallurgic slags (granulated and air-cooled) in making blended slag cement with ordinary Portland cement was investigated by Rai et al. (2002). The results, which indicated that slag could be used with slight modifications as non-

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structural concrete, provided a direction for profitable plans for making blended slag cements. Blast furnace slag aggregate (BFSA) was used by Demirboga and Gu¨l (2006) for producing high-strength concretes (HSC). Their results showed that the compressive strength of BFSA concretes was approximately 60–80% higher than that of traditional concretes. These concretes also had low absorption and high splitting tensile strength values. Askari and Najafi (2017) studied applying solid residues of copper slag in kerman Sarcheshme of Iran as sand replacement for self-compacting concrete. They concluded that the 28-days compressive strength by replacing sand with 20, 40 and 60% copper slag respectively increased to 11.3%, 15.5% and 12.4%.

Until the early 1980s, shortage of skilled labor for compacting concrete structures was recognized as the most important factor in reducing the durability and effective performance of such structures in Japan. For this reason, Okamura (1996; 1997; 1999; 2000; 2005), professor of the Kochi University of Technology in Japan, after many experiments could achieve concrete construction technology, that compression operation did not depend on the skill of the construction worker and could be dense under its own weight (Dolatabad and Maghsoudi, 2014). This type of concrete itself can achieve a high level of compactness without applying external energy. According to the definition of ACI237R-07 (2013), self-compacting concrete is high-performance concrete without any segregation that can be poured into the desired area and fill the mold space with dense reinforcement without any mechanical compaction. EFNARC (2005) defines SCC as a type of concrete that is 'able to flow under its own weight and completely fill the formwork, even in the presence of dense reinforcement, without the need of any vibration, while maintaining homogeneity'. When we used lightweight aggregates in construction of this type of concrete, it becomes lightweight self-compacting concrete (LWSCC). LWSCC is a kind of high performance concrete developed by combining the favorable properties of self-compacting concrete (SCC) and lightweight (Güneyisi et al., 2016). In the literature there are many studies on the use of lightweight aggregate (LWA) in the production of SCC (Gonen and Yazicioglu, 2018; Aslani and Kelin, 2018; Li et al., 2017) and most of them are usually focused on the workability or rheological properties and mechanical properties of lightweight self-consolidating concrete (LWSCC). The effect of mineral admixtures and wastes on the rheological and mechanical properties of LWSCC has been investigated very few yet. Güneyisi et al. (2012) investigated fresh properties of self-compacting cold bonded fly ash lightweight aggregate concrete with different mineral admixtures and concluded that incorporating the mineral admixtures improved fresh properties of SCLWCs. Slump flow time of the concretes containing any of the mineral admixtures was shorter than that of the control mixture with only PC. Mixture proportioning and properties of self-consolidating lightweight concrete containing glass powder was studied by Shi and Wu (2005). Their results show that the use of ground glass powder as a cement replacement can effectively reduce the chloride permeability of the concrete, which can be attributed to the fact that glass powder has higher pozzolan reactivity than the fly ash.

Research significance

Due to its various advantages, mainly high strength/weight ratio, no need to vibrate and ease of production, LWSCC is recognized as a special type of concrete for construction industry (Andiç-Çakır and Hızal, 2012). Many studies was done on the use of mineral wastes in the mixtures of concrete, but no study has been done about the use of Sirjan iron mine waste (SIMW) in light weight self-compacting concrete (LWSCC). For this purpose, SIMW is used, and the effect of this mineral admixture inclusion on the fresh, mechanical and transport properties of LWSCC is studied. Slump flow, flow time, V-funnel and L-box tests are performed to assess workability. Moreover, the compressive, flexural, splitting and bond strengths, absorption, porosity, sorptivity and rapid chloride permeability of lightweight self-compacting concrete mixtures incorporating different SIMW content (0%, 5%, 10% and 15% by weight of cement) are also determined at 28 days.

Experimental program

Material

The materials used to develop the LWSCC in this study were river sand as fine aggregate, LECA as light weight aggregate, type II Portland cement complying with the requirement of ASTM C150 (2001) and silica fume. Crushed sand with a maximum diameter of 4.76 mm, a fineness modulus of 2.71, a total moisture content of 0.1%, water absorption of 3.2% and a specific gravity of 2.71 g/cm^3 was used. LECA aggregates were used to decrease the weight of self-compacting concrete. LECA aggregates were produced from expanded clay (produced in rotary kilns at temperatures of about 1200 ^{o}c in Shahre Babak mines). The maximum diameter of light weight aggregates (LWA) was 12.5 mm and the specific gravity of LWA was 925 kg/m^3. Figure 1 shows the aggregate gradient graph of the fine aggregate and LECA used.

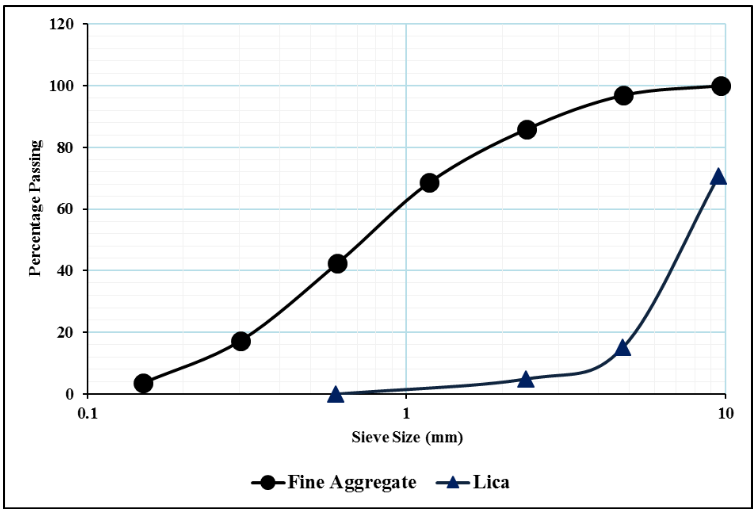


Figure 1. The grain size distribution curve of fine and light weight aggregates

The silica fume with a specific gravity of 1.95 gr/cm^3, a pH of about 9 and a dark gray color was added to improve segregation resistance. Chemical composition and physical properties of cement and silica fume are given in Table 1. Polycarboxylic ether based high range water reducer (HRWR) Glenium51 with density 1.13 g/cm^3 and a solids content of 40.2% was used to enhance the flowability of the mixtures.

Table 1. Chemical composition and physical properties of cement, silica fume and SMIW.

Chemical composition	L.O.I	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Cl	I.R.
Cement (%)	1.33	21.7	4.62	3.95	65.04	1.25	2.78	0.61	0.62	0.019	0.46
Silica fume (%)	1.9	91	0.9	1.25	0.85	1.9	-	0.7	1.6	-	-
SMIW (%)	6.2	39.952	5.907	22.174	9.249	14.16		1.855	0.937	-	-

Physical Characteristics of cement

Compressive strength (MPa)			Time of setting (min)		Blaine fineness (cm^2/g)	Specific gravity	Autoclave expansion (%)
3 days	7 days	28 days	Initial	final			
26.3	34.3	44.9	140	190	2950	3.12	0.19

In this research, Sirjan Gol Gohar iron mine waste (Figure 2) was used to replace cement different percentages. Chemical composition of SIMW was obtained based on the X-ray Fluorescence (XRF) analysis results. Chemical composition of SIMW was given in Table 1.

Figure 2. Sirjan Gol Gohar iron mine waste

Mixing plan

In this study, a total of 5 mixtures were designed to have a constant water to binder (the sum of cement, silica fume and SMIW) ratio of 0.38. The amount of silica fume was 13 wt% of the cement in all mixtures, which was determined through preliminary trials. The mixtures were designed to give a slump flow diameter of 650–800 mm, which was attained by amounts of SP (1.5 wt% of the cement). LWSCC-IW5, LWSCC-IW10, LWSCC-IW15 and LWSCC-IW20 denote the concrete containing 5 wt%, 10 wt%, 15 wt% and 20 wt% SMIW, by the weight of cement, respectively. The mixture proportions of LWSCC's are given in Table 2.

Table 2. Mix proportions for LWSCC's

Mix No.	Sand (kg/m3)	Lica (kg/m3)	Cement (kg/m3)	Water (kg/m3)	Superplasticizer (kg/m3)	Micro Silica (kg/m3)	SMIW(kg/m3)
LWSCC	708	460	479	206	7.033	62	0
LWSCC-IW5	708	460	455.05	206	7.033	62	23.95
LWSCC-IW10	708	460	431.1	206	7.033	62	47.9
LWSCC-IW15	708	460	407.15	206	7.033	62	71.85
LWSCC-IW20	708	460	383.2	206	7.033	62	95.8

Immediately after mixing of the concrete, In order to evaluate the filling ability, passing ability, stability and viscosity of the self-compacting concrete, according to the EFNARC (2005) criteria, Slump Flow, J-Ring, T_{500}, V-Funnel, U-Box and L-Box tests were carried out.
After validation of tests, all LWSCCs specimens were cast without any compaction or mechanical vibration. Forty-five 10×10×10 cm cubic samples were prepared for compressive strength at 3, 7 and 28 days. Forty-five 10×20 cm cylindrical samples were prepared for tensile strength at 3, 7 and 28 days and fiveteen15×15×15 cm cubic samples for conducting permeability tests. Thirty 50×50×500 cm flexural samples were prepared for flexural strength at 3, 7 and 28 days. After casting, all the specimens were covered with plastic sheets, and left

at room temperature for 24 hours. Then, they were demolded and transferred to the moist curing room and maintained at 22 ± 2 ^{0}C and 100% relative humidity until testing.

Results of fresh concrete tests

Slump flow diameter value describes the flowability of a fresh mix in unconfined conditions (EFNARC, 2005). The slump flow results in Table 3 indicate that the diameter of SCLC slump flow was 685–750 mm. It is clearly seen that the slump flow diameter decreased as the percentage of replacement SMIW increased. When the slump-flow values given by EFNARC were considered (650–800 mm), we can conclude that a good flowability was obtained for all the mixtures.

Viscosity can be assessed by the T_{500} time during the slump-flow test or assessed by the V-funnel flow time. The change of the T_{500} time and V-funnel flow time of LWSCCs with different percentages of replacement SMIW was shown in Table 3. T_{500} for all mixes ranged between 1.8 and 3.5 s and V-funnel flow time for all mixtures was between 8-10 s. It was observed that the addition of SMIW decreases T_{500} and V-funnel flow time. Addition of SMIW decrease viscosity of the mixtures but all of the mixtures were in the allowable range given by EFNARC (6–12 s).

Table 3. Results of fresh concrete tests

Mix No.	Slump Flow (mm)	V Funnel (s)	J Ring (h2-h1) (mm)	U Box (h2-h1) (mm)	L Box (h2/h1)	T_500 (s)
LWSCC	750	8	10	5	1	1.8
LWSCC-IW5	739	8.2	11	9	0.98	2.4
LWSCC-IW10	730	8.5	12	11	0.92	2.5
LWSCC-IW15	716	9.1	13	15	0.85	2.4
LWSCC-IW20	685	10	13	21	0.8	3.5

Ability of mixtures to flow through tight openings, such as spaces between steel reinforcing bars without segregation or blocking was measured by J-Ring, L-Box and U-box tests. As shown in Table 3, the J-Ring height difference for mixtures ranged between 10 and 13 mm and U-Box height difference ranged between 5 and 21 mm. The L-box height ratio for all mixtures was greater than 0.8. Adding SMIW to the control mixture decrease the passing ability but, as shown in Table 3, H2 /H1 ratio met the EFNARC (2005) limitation (0.8-1) for all mixtures.

Compressive strength

The development of compressive strength of LWSCCs containing different dosage of SMIW is given in Figure 3, showing the strengths at 3, 7 and 28 days. It was observed that compressive strength of LWSCC increased by improving the age of concrete. As shown in Figure 3 , all mixtures exhibited a 7-day compressive strength greater than 16 MPa and 28-day compressive strength greater than 25 MPa, thus satisfying ACI 213R (2003) for minimum compressive strength of structural lightweight concrete. The range of strength varied from 14 to 24 MPa at 3 days, from 16 to 25 MPa at 7 days and from 25 to 42 MPa at 28 days, depending on SMIW content. By adding 5 wt% SMIW, the 3-day compressive strength of the SCCLWs increased to 10.5%, 7 days to 15%, and 28 days to 9%, compared to control samples. Also, with 10 wt% SMIW, the compressive strength at 3, 7 and 28 days increased by 26, 25 and 20%, respectively.

By adding 15wt% SMIW, 3, 7 and 28 days compressive strength of mixtures decreased 16%, 10% and 14%, respectively, compared to control mixture. Compressive strength of mixtures containing 20wt% SMIW decreased by 26%, 20% and 29% at 3,7 and 28 days, respectively, compared to the control mixtures. As shown in Figure 3, the mixture containing 10 wt% SMIW has the highest compressive strength compared to other mixtures. It was observed that adding SIMW, as substitute part of cement, to 10 wt% can increase the compressive strength of LWSCCs.

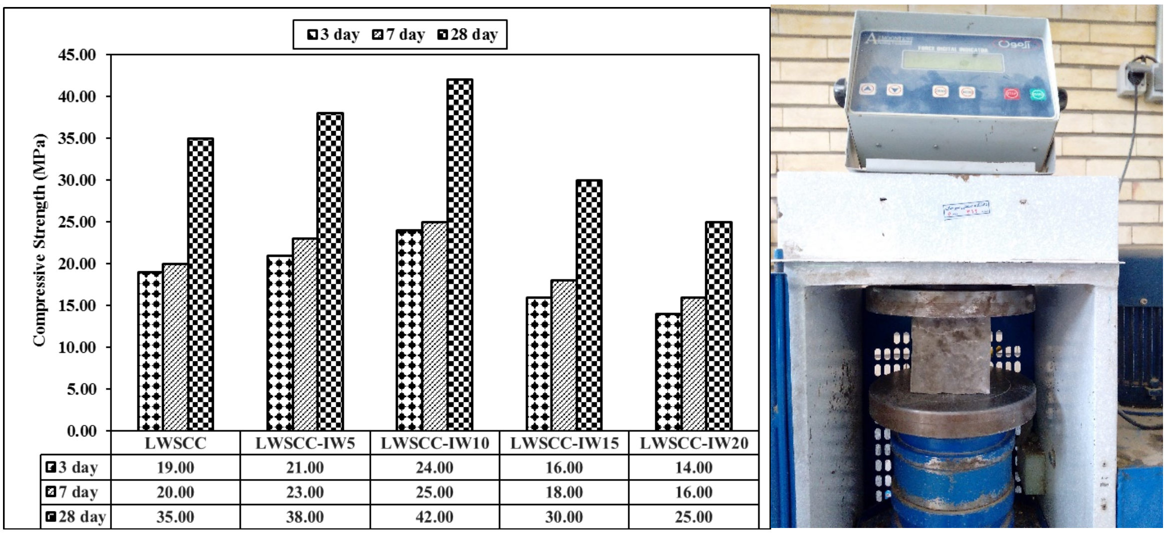


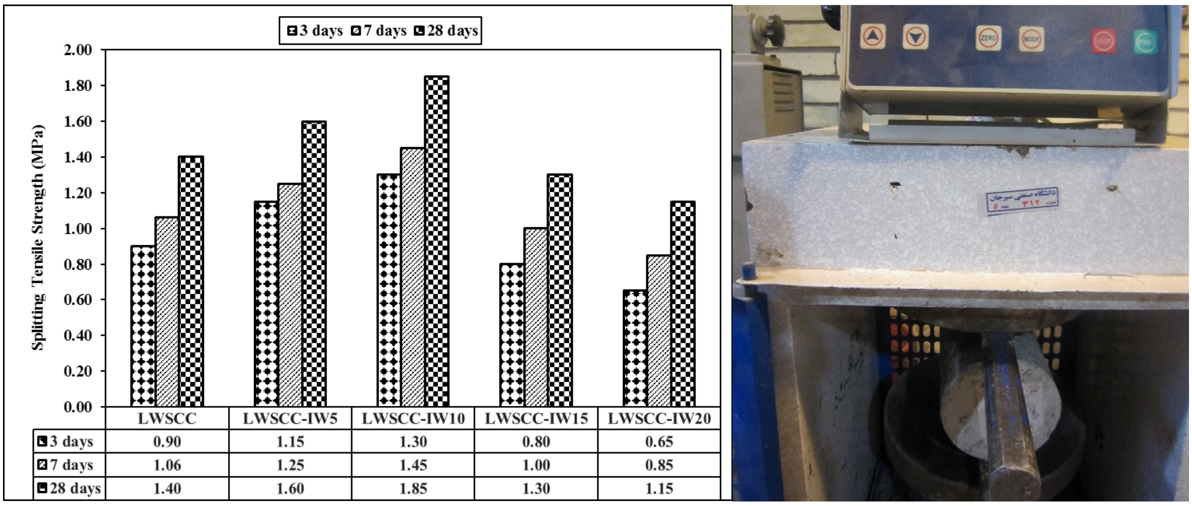
Figure 3. Variation of compressive strengths of LWSCCs containing SMIW at different ages.

Splitting tensile strength

Figure 4 shows the splitting tensile strength at different ages for light weight self-consolidating concrete containing different dosage of SMIW. The 28-days splitting tensile strength of the control self-consolidating concrete having zero SMIW content was 1.4 MPa and the 28-days splitting tensile strength of the lightweight SCC containing 5 and 10wt% SMIW was found to be 1.6 and 1.85 MPa, respectively. In particular, the 28-days splitting tensile strength of self-consolidating concrete that used 5 and 10wt% of SMIW was 14 and 32% higher than that of the control mix, respectively. By increasing SMIW to 15 and 20wt%, the tensile strength of mixtures at 28 days decreased 7 and 17% compared to the control mixture. Increase in splitting tensile strength at 7 days for all mixtures was greater than 3 days and 3 days was greater than 28 days.

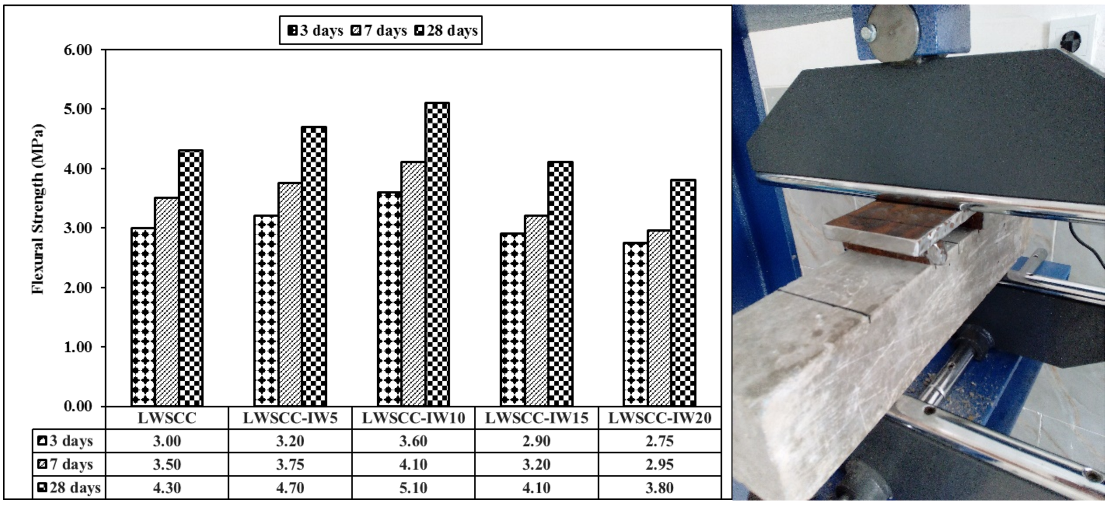
Flexural strength

According to the study, all of the mixtures ruptured at two points at 3, 7 and 28 days. The test results of the maximum force on the sample and the calculated stage of rupture is named rupture module (R) (Mazaheripour et al., 2011) and are shown in Figure 5. The rupture module for the control sample, with 0wt% SMIW, at 3, 7 and 28 days was 3, 3.5 and 4.30 MPa. By adding 5 wt% SMIW, the 3-day rupture module of the SCCLW's increased to 6.7%, 7 days to 7.1%, and 28 days to 9.3%, compared to control samples . Also, with 10 wt% SMIW, the rupture module at 3, 7 and 28 days increased by 20, 17.1 and 18.6%, respectively. By adding 15wt% SMIW, 3, 7 and 28 days rupture module of mixtures decreased 3.3%, 8.6% and 4.6%, respectively, compared to control mixture. Rupture module of mixtures containing 20wt% SMIW decreased by 8.3%, 15.7% and 11.6% at 3,7 and 28 days, respectively, compared to the control mixtures.



	LWSCC	LWSCC-IW5	LWSCC-IW10	LWSCC-IW15	LWSCC-IW20
3 days	0.90	1.15	1.30	0.80	0.65
7 days	1.06	1.25	1.45	1.00	0.85
28 days	1.40	1.60	1.85	1.30	1.15

Figure 4. Variation of splitting tensile strength of LWSCCs containing SMIW at different ages.



	LWSCC	LWSCC-IW5	LWSCC-IW10	LWSCC-IW15	LWSCC-IW20
3 days	3.00	3.20	3.60	2.90	2.75
7 days	3.50	3.75	4.10	3.20	2.95
28 days	4.30	4.70	5.10	4.10	3.80

Figure 5. Variation of flexural strength of LWSCCs containing SMIW at different ages.

Water Penetration

The water penetration depth of the mixtures at 28 days after curing was shown in Figure 6 In all mixtures. By adding 5wt% SMIW to the control mixture, the water penetration depth at 28 days after curing decreases 20%. By increasing the content of SMIW to 10wt%, the water penetration depth at 28 days decreases 7.5%. The water penetrability of LWSCC-IW15 at 28 days was 5% higher than LWSCC. It was observed that an increase of 20wt% SMIW cause that the water penetrability depth increases 30% at 28 and days. It was observed that adding SMIW to 10wt%, as substitute part of cement, can improve durability of light weight self-consolidating concrete.

Conclusion

In this paper, results from a study of the influence of Sirjan mine iron waste (SMIW) on the workability, mechanical properties and durability of light weight self-consolidating concrete have been presented. Based on the experimental results, the following conclusions can be drawn.

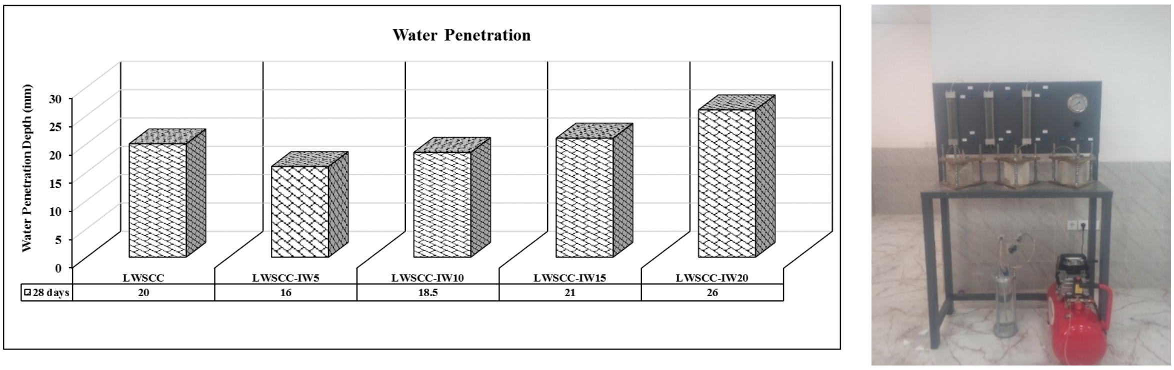


Figure 6. Water penetration depth of LWSCCs containing SMIW at 28 days age.

1- The use of SMIW as substitute part of cement caused the slump flow diameter decreased and flowability times of T_{500} and V-funnel tests increase very little because of the addition of SMIW enhanced the consistency of the LWSCCs. All the mixtures containing SMIW had blocking ratio between 0.8 and 1. All the mixtures containing SMIW satisfied the requirements of SCC with respect to EFNARC [20]. Thus, all the mixtures containing SMIW are assumed to have good flowability, filling ability, passing ability and resistance to segregation.
2- By adding 5wt% SMIW, the 3d, 7d and 28d-strength of LWSCCs increased by 10.5%, 15% and 8.6%, respectively. Using 10wt% SMIW as replacement of cement caused the compressive strength of LWSCCs increase 26%, 25% and 20% at 3, 7 and 28 days, respectively. By using 15wt% and 20wt% SMIW as cement replacement, the 3d, 7d and 28d-strength of LWSCCs decreased by 15.8%, 10%, 14.3% and 26.3%, 20%, 28.6%, respectively.
3- The splitting tensile strength and rupture modules of LWSCCs increased with the addition of SMIW to 10% then decreased. There was an increase of splitting tensile strength approximately 44.4%, 36.8% and 32.1% at 3, 7 and 28 days and increase of rupture modules approximately 20%, 17.1% and 18.6% at 3, 7 and 28 days, respectively for 10wt% replacement of SMIW.
4- Maximum and minimum penetrability depth was observed for sample containing 15wt% and 20wt% SMIW. So, we can conclude that adding SMIW to 10% can improve durability of LWSCCs.

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