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Study Mechanical Properties of Self-Compacting Concrete with Pozzolanic Additives Under Different Curing Conditions

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***Abstract*:- Self-compacting concrete is a development of conventional concrete, where the use of vibrators for compaction is no more required. The utilization of industrial by-products is gaining momentum with increasing environmental awareness and the need to mitigate hazardous effects of industrial wastes. The paper focused on the feasibility of substituting the ordinary Portland cement with waste supplementary cementing materials that is, fly ash and silica fume. Four mixes were prepared with proportions of 10% and 15% of fly ash and silica fume by weight of cement in to be compared with a reference mix with 100% Portland cement. Some specimens were cured in water for 7 and 28 days, the other specimens were left in air for 28 days. compressive strength test, splitting tensile strength test and flexural strength test were performed after curing in water and air. The slump flow, V-funnel and segregation resistance test are carried out on the fresh self-compacting concrete. Test results have reflected that the compressive strength, tensile strength and flexural strength achieved maximum increase with 15% silica fume as a partial replacement of cement. Compressive strength and flexural strength increased with 15% silica fume by 12.82% and 19.2%, respectively at 28 days age compared to compressive strength and flexural strength of control mix. There is significant development in mechanical properties for mixes prepared with fly ash and silica fume compared to control mix. The mechanical properties of self-compacting concrete were higher for all specimens cured in water than those cured in air at age of 28 days.**

Keywords- Self-compacting concrete; compressive strength; flexural strength; curing conditions; Silica fume

I. INTRODUCTION

Self-compacting concrete (SCC) is a viscous mixture suitable for casting intricate structures and structures with congested reinforcement, without or with slight vibration, while maintaining a consistent flow free from segregation and bleeding [1]. Self-compacting high-performance concrete was used with partial replacement of Portland cement with fly ash and silica fume in exploring the fresh properties and compressive strength of six different SCHPC mixes. The blend of 40% PC, 50% FA, and 10% SF achieved a maximum compressive strength at 28 days curing age [2]. Two supplementary materials are used Fly Ash and Metakaoline. The controlled designed mix only ordinary Portland cement as a binder while the remaining mixtures are incorporated ternary blends of OPC, Metakaoline and Fly ash. The test result investigated the effective increments of mechanical properties with the blends and achieving the standard properties of SCC [3]. The inclusion of rice husk ash in self-compacting concrete as replacement of cement does not affect the strength properties negatively as the strength remains within limits up to 20%replacement. Inclusion of RHA showed great improvement in durability properties of concrete [4]. To develop SCC with locally available waste materials. Coal ash and wood ash were used as partial cement replacement to achieve strength similar to normal concrete. It was observed that all SCC mixes without any cement replacement by coal ash and wood ash exhibited greater values in both split tensile and compressive strength compared to normal concrete. The optimum percentage of partial cement replacement in SCC by both wood ash and coal ash to achieve strength similar to that of conventional normal concrete at a particular w/c ratio was found to be 10% [5]. Fibers are introduced in SCC to get multiplied overall performance ordinarily in flexure, impact, and additionally in compressive strength. The results of workability the slump flow and blocking ratio is decreasing with increasing % crimped steel fibers in SCC mixes in associated SCC mixes due to that viscosity time is increasing [6]. Characteristic influence of carbon fibers (CFs) on the fresh state (filling ability, passing ability and resistance to segregation) and hardened state (compressive and tensile strength) of self-compacting concrete (CFBSCC) was studied. The compressive strength was increased to a maximum of 24.5% with the inclusion of 1%CF to 1.5%CF. The variations in the splitting tensile strength varied from a maximum increase of 7.78% at 1%CF to a maximum decrease of 8.67% at 2%CF [7]. Industrial by-products like waste foundry sand, coal bottom ash, waste tire rubber, copper slag, and waste glass were used as fine aggregate replacement in the development of green self-compacting concrete. These industrial by-products have a great potential to be utilized in self-compacting concrete, leading to sustainable development [8]. The findings indicated that the incorporation of the roselle fiber reduced the workability behavior of the self-compacting concrete. By contrast, the mechanical characteristics, such as compressive strength, splitting tensile strength, modulus of rupture and modulus of elasticity were enhanced with increasing fiber content. However, 4% fiber addition resulted in a marginally decreased compressive strength and modulus of elasticity of the self-compacting concrete [9]. Eleven concrete mixes were prepared in order to vary the substitution rate by

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weight of natural aggregates by recycled aggregates. The substitution rates were set at 50% and likewise, the cement has also been substituted from 5% to 20% by weight by natural pozzolan (NP). The results indicate that recycle SCC mixes that contain NP has a beneficial effect on the capillary dimension of the hardened cement paste, since the capillary absorption provides information on the rise of water through the open porosity of the concrete produced by the tension superficial liquid. The presence of NP reduces capillary pores by filling these pores with second-generation CSH gel formed from pozzolan silica and portlandite, the hydrate resulting from the hydration of cement [10]. One of the disadvantages of self-compacting concrete is its cost, associated with the use of high volumes of Portland cement and use of chemical admixtures. One alternative to reduce the cost of self-compacting concrete is the use of mineral admixtures such as silica fume, ground granulated blast furnace slag and fly ash. When these mineral admixtures replace a part of the Portland cement, the cost of self-compacting concrete will be reduced especially if the mineral admixtures are waste or industrial by-product. Moreover, the use of mineral admixtures in the production of self-compacting concrete not only provides economic benefits but also reduces heat of hydration [11].

II. WORK OBJECTIVE

The main objective is to improve the mechanical properties of self-compacting concrete and to find environmentally friendly and economical application of the abundant fly ash generated from the coal-powered electricity generating plants and silica fume which is a by-product of producing ferrosilicon alloys.

III. EXPERIMENTAL WORK

Materials

The different materials used in this investigation are: -

Cement: Ordinary Portland (CEM-I) cement with grade 42.5 N confirmed Egyptian Standard Specifications (ESS) requirements (4756-1/2007).

Fine Aggregate: Medium well-graded sand of fineness modulus 2.85 was used for concrete complies an Egyptian Standard Specifications (ESS) requirement (ECP.1109/2002).

Coarse aggregate: Crushed dolomite was used as coarse aggregate. Maximum nominal size of coarse aggregate was 12.7 mm.

Water: Fresh tap water was used for both mixing and curing purposes.

Chemical additives: Sika ViscoCrete-5930 is a third-generation super plasticizer for concrete. It meets the requirements for super plasticizer according to ASTM-C-494 Types G and F.

Fly Ash: FA meets the general requirements of ASTM C618 Class F. TABLE I. presents the chemical composition and physical characteristics of fly ash.

TABLE I. THE CHEMICAL COMPOSITION AND PHYSICAL CHARACTERISTICS OF FLY ASH.

Parameters	values
SiO_2	87.2%
Fe_2O_3	0.16%
Al_2O_3	0.15%
Cao	0.55%
MgO	0.35%
SO_3	0.24%
C	5.91%
L.O.I.	5.44%
Fineness passing 45 microns	96%
Mineralogy	Non crystalline
Shape	Irregular

The tests were performed on FA and SF at National Research Center for Housing and Buildings Cairo, Egypt.

Silica fume (SF): TABLE II. presents the physical and chemical properties of silica fume.

TABLE II. THE PHYSICAL AND CHEMICAL PROPERTIES OF SILICA FUME.

Chemical composition%	
Constituent	Content (%)
SIO_2	91.4
FeO_3	0.3-0.5
Al_2O_3	1.1
CaO	0.7
MgO	1.3
SO_3	0.4
K_2O	0.5
Na_2O	0.8
Physical properties	
Specific gravity	2.2
Specific area cm^2/gm	200000

Concrete Mixes

The concrete mixture was weighed and mixed in mechanical mixer for 2 min. The concrete mixture was cast in steel molds for different tests. Test specimens were demolded after 24 hours and were cured. Five binder mixes were prepared involve a control mix with 100% Portland cement and without FA and SF, two mixes were prepared with 10% and 15% of fly ash (FA) by weight of cement and the other two mixes were prepared with 10%,15% of silica fume (SF) by weight of cement. w/c ratio of 42%. The used dosage of ViscoCrete-5930 was 1% by weight of cement. Materials required per cubic meter of self-compacting concrete are shown in Table III.

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TABLE III. MIX DESIGN (Kg/m^3).

Mix	W/C	Water	Cement	FA	SF	Coarse aggregate	Fine aggregate	Plasticizer Sika ViscoCrete-5930
Control			500	-	-			
M1 (10%FA)			450	50	-			
M2 (15%FA)	0.42	210	425	75	-	655	976	5
M3 (10%SF)			450	-	50			
M4 (15%SF)			425	-	75			

IV. TESTING

Fresh Concrete

Slump Flow Test and T500 time

To evaluate the ability of SCC in the flowability, the slump-flow test is carried on the fresh SCC. In slump test, the cone is filled with concrete and then lifted vertically and the time measurement is started. The spread diameter T500 (i.e., the time of flow to reach a diameter of 500 mm) and the general visual appearance of the concrete are recorded [12].

V-funnel Test

To evaluate the ability of SCC in the viscosity, V-funnel test is carried on the fresh SCC. The test is carried out by filling a funnel with about 5 of concrete mixtures and then measured the time in seconds that the concrete takes to drain of the funnel [12].

Segregation Resistance Test

The sieve stability test was conducted of fresh concrete. The test aims to determine how likely a SCC mix is to segregate by allowing a 10 L concrete sample to undergo static segregation for 15 minutes (in a bucket). Then the top layer of the sample (4.8 kg ± 0.2) is poured onto a 5 mm sieve and some mortar passes through the sieve. The potential segregation is expressed as the ratio between the mass of mortar collected through the 5 mm sieve and the initial mass of the top layer. More mortar passing through the sieve indicates a greater liability to segregation [12].

Compressive Strength Test

The compression test was conducted of the prepared concrete. The cube specimens with dimensions of 15*15*15 cm were cast. All specimens were provided with sufficient time for hardening (24 hours) and cured with two cases of curing methods in water and air. For each age, three (3) specimens were prepared. After the specified period (7and 28 days) all the specimens were tested for its maximum load in the compression testing machine. The cubes were tested on hydraulic machine 1500 kN capacity [13].

Flexural Strength Test

Flexural strength test was carried out on prisms with dimensions 10*10*50 cm on flexure testing machine under four points loading. For each age, three (3) specimens were prepared and cured with two cases of curing methods in water and air. The strength was analyzed for 7and 28 days. The flexural strength is calculated from the equation (1) as given below [14, 15]: -

Flexural strength $=PL/d1d_2^2$ (1)

Where, P the maximum applied load to the specimen (N), d1 the width of the specimen (mm), d2 the depth of specimen (mm).

Splitting Tensile Strength

The cylinder specimens with dimensions of 15*30 cm were tested on compression testing machine. The bearing surface of machine was cleaned and other sand or other materials were removed from the surface of the specimen. For each age, three (3) specimens were prepared and cured with two cases of curing methods in water and air. The strength was analyzed for 7and 28 days. The load applied was increased continuously. The tensile strength is calculated from the equation (2) as given below [16]: -

Tensile strength$=2P/\pi DL$ (2)

Where, P the maximum applied load to the specimen (N), D diameter of cylinder, L length of cylinder.

V. RESULTS & DISCUSSION

Fresh Concrete

Slump Flow Test and T500 time

The results of the slump flow test are presented in *Fig. 1*. The results represent the maximum spread (the final diameter of slump flow). The European Specification of SCC recommends that concrete mixtures should have slump flow diameters of 52 cm to 90 cm. Slump flow that exceeds a 90-cm diameter may cause concrete to segregate, whereas that with less than a 52cm diameter may indicate concrete with flow rates that are insufficient for passing through an overcrowded reinforcement. Slump flow of four concrete mixes with FA and SF exhibited low slump flow compared to control mix. SCC mix with 15% SF as a replacement of cement content give lowest values of slump flow. This is may be due to the physical properties of fly ash and silica fume, as they are characterized by an increase in their surface area which leads to the absorption of part of mixingwater. The results of the flow time test are presented in *Fig. 2*. The results show that T500 increase in four concrete mixes with FA and SF compared to control mix. SCC mix with 15% SF as a replacement of cement content give maximum value of T500. The values of T500 match with The European Specification of SCC, 2005.

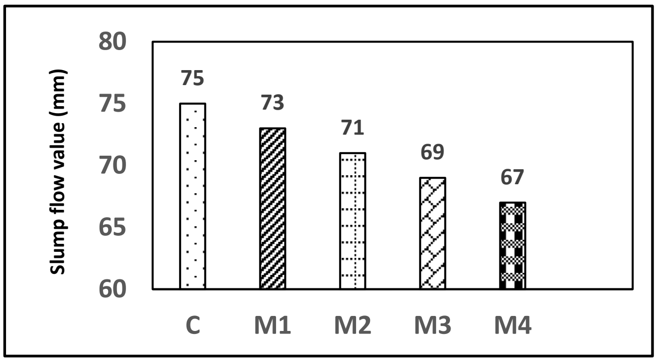


Fig. 1. Slump flow test for different mixes

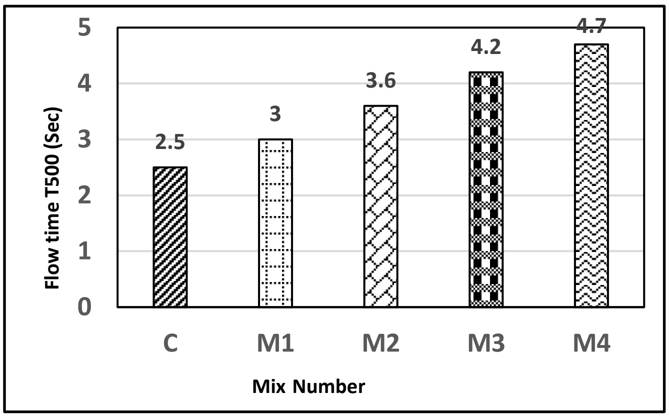


Fig. 2. Flow time(T500) for different mixes

V-funnel Test

The V-funnel flow time was calculated in seconds between the time of the beginning of opening the bottom outlet until the light became noticeable from the bottom outlet. European Specification of SCC, 2005 recommends that SCC should have V-funnel flow times ≤10 seconds. The results indicated increase of v-funnel flow time for four concrete mixes with FA and SF compared to control mix. SCC mix with 15% SF as a replacement of cement content gives maximum value of v-funnel flow time as shown in *Fig. 3*.

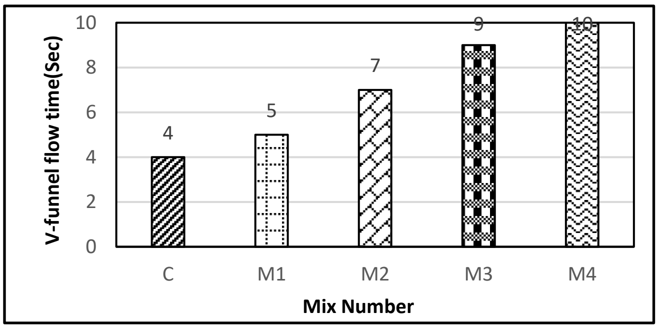
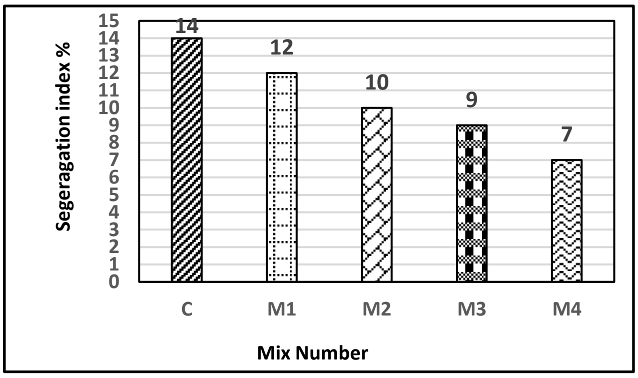


Fig. 3. V-funnel flow time for different mixes

Segregation Resistance Test

The results of the segregation resistance test are presented in *Fig. 4*. The segregation decreases for four concrete mixes with FA and SF compared to control mix. SCC mix with 15% SF as a replacement of cement content gives lowest value of segregation. The higher ratio of FA and SF the lower the segregation index of SCCs. The values of segregation match with The European Specification of SCC, 2005 which are≤18.

Fig. 4. Segregation index for different mixes



Hardened concrete

Compressive Strength Test

The obtained values of concrete compressive strength according to the different used percentage of FA and SF are shown in TABLE IV and the graphical representation in *Fig. 5.* These figures indicate that, the higher the percentage of FA and SF the higher the values of compressive strength. SCC mix with 15% SF as a replacement of cement content gives maximum value of compressive strength at age of 28 days compared to compressive strength for control mix, it is increased by 12.82% of compressive strength for control mix while compressive strength of 15% FA as partial replacement of cement increased by 5.13% of compressive strength for control mix. This is due to FA and SF have unique pozzolanic property. They have SiO_2 which reacts with $Ca(OH)_2$ that forms from the hydration of calcium silicates in cement resulting calcium silicate hydrate(CSH), which is responsible for the strength in cement-based materials. Compressive strength for all specimens cured in water was higher than compressive strength of specimens cured in air at age of 28 days as shown in *Fig. 6*. SCC mix with 15% SF gives maximum value of compressive strength in case of specimens cured in water compared to compressive strength of specimens cured in air, it is increased by 15.5% of compressive strength of the mix with the same ratio.

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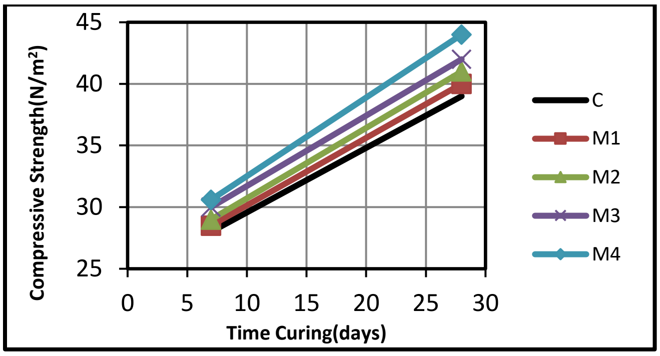

Fig. 5. Compressive strength for different mixes in case of curing in water

TABLE IV. COMPRESSIVE STRENGTH (N/mm^2) FOR DIFFERENT MIXES IN CASE OF CURING IN WATER

Mix	Compressive Strength (N/mm2)	
	Age(days)	
	7 days	28 days
C	28	39
M1	28.5	40
M2	29	41
M3	30	42
M4	30.6	44

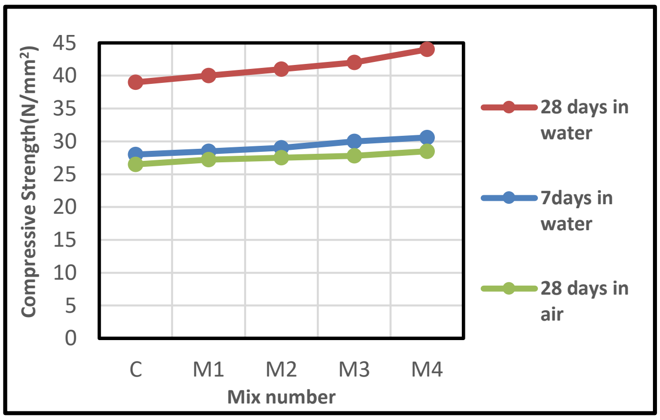

Fig. 6. Effect of curing conditions on compressive strength

Flexural Strength Test

The results of the flexural strength are represented in TABLE V and the graphical representation is shown in *Fig. 7*. At age of 7 and 28 days, flexural strength increased for different percentages of FA and SF compared to flexural strength for control mix. At age of 28 days, flexural strength of 15% SF had maximum increase; it is increased by 19.2% of flexural strength for control mix. It can deduce that partial replacement of cement by FA and SF could enhance flexural strength compared to flexural strength of control mix. Flexural strength for all specimens cured in water was higher than flexural strength of specimens cured in air at age of 28 days as shown in *Fig. 8*. SCC mix with 15% SF gives maximum value of flexural strength in case of specimens cured in water compared to flexural strength of specimens cured in air, it is increased by 29.2% of flexural strength for the mix with the same ratio.

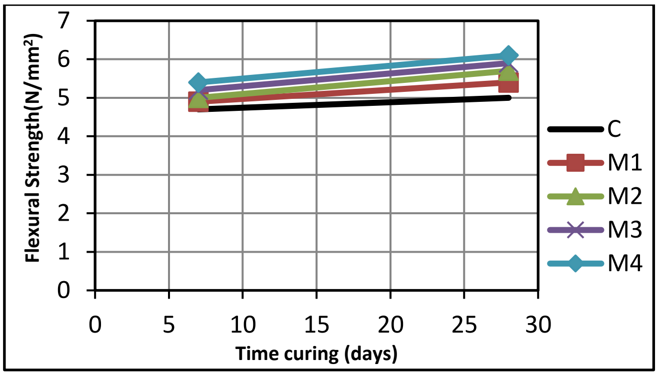

Fig. 7. Flexural strength for different mixes in case of curing in water

TABLE V. FLEXURAL STRENGTH (N/mm^2) FOR DIFFERENT MIXES IN CASE OF CURING IN WATER

Mix	Flexural Strength (N/mm2)	
	Age(days)	
	7 days	28 days
C	4.7	5.2
M1	4.85	5.5
M2	5	5.7
M3	5.2	6
M4	5.4	6.2

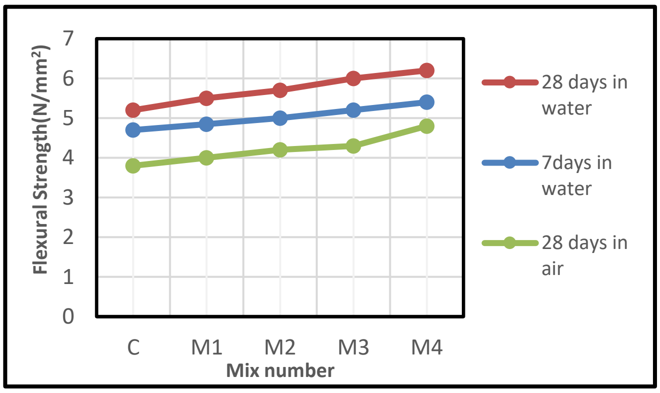

Fig. 8. Effect of curing conditions on flexural strength

Splitting Tensile Strength

The influence of partial replacement of cement by FA and SF on the splitting tensile strength of concrete samples was investigated. At age of 7 and 28 days, splitting tensile strength increased for different percentages of FA and SF compared to splitting tensile strength of control mix as shown in *Fig. 9* and TABLE VI. At age of 28 days, splitting tensile strength of 15% SF had maximum increase; it is increased by 28.6% of splitting tensile strength for control mix. Splitting tensile strength for all specimens cured in water was higher than splitting tensile strength of specimens cured in air at age of 28 days as shown in *Fig. 10*. SCC mix with 15% SF gives maximum value of splitting tensile strength in case of specimens cured in water compared to splitting tensile strength of specimens cured in air, it is increased by 21.6% of splitting tensile strength for the mix with the same ratio.

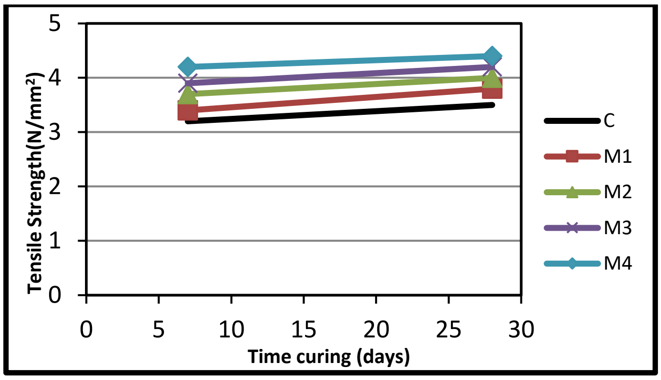

Fig. 9. Splitting tensile strength for different mixes in case of curing in water

TABLE VI. SPLITTING TENSILE STRENGTH (N/mm^2) FOR DIFFERENT MIXES IN CASE OF CURING IN WATER

Mix	Splitting tensile strength (N/mm^2) Age(days)	
	7 days	28 days
C	3.2	3.5
M1	3.4	3.6
M2	3.7	4.1
M3	4	4.3
M4	4.2	4.5

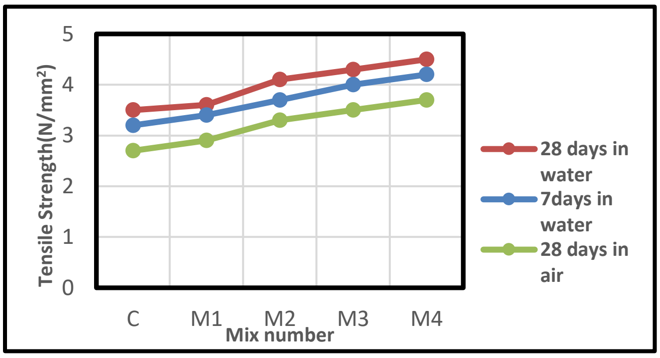

Fig. 10. Effect of curing conditions on splitting tensile strength

CONCLUSIONS

From the experimental study it can be concluded that:

1. Fly ash and silica fume improved compressive strength of SCC compared to compressive strength of control mix. Compressive strength increased with 15% SF and 15%FA as a replacement of cement content by 12.82% and 5.13%, respectively at 28 days age compared to compressive strength of control mix.
2. Flexural strength increased for different percentages of FA and SF compared to flexural strength of control mix. At age of 28 days, flexural strength of 15% SF had maximum increase; it is increased by 19.2% of flexural strength for control mix.
3. Splitting tensile strength increased for different percentages of FA and SF compared to splitting tensile strength of control mix. At age of 28 days, splitting tensile strength of 15% SF had maximum increase; it is increased by 28.6% of splitting tensile strength for control mix.
4. Different percentages of FA and SF affected on flowability of SCC, the slump flow value for different percentages of FA and SF decreased and T500 value increased. The values of slump flow and T500 for all mixes match with The European Specification of SCC, 2005.
5. Different percentages of FA and SF affected on the ability of SCC in the viscosity. V-funnel flow time for four concrete mixes with FA and SF increased compared to control mix. The values of v-funnel for all mixes match with The European Specification of SCC, 2005.
6. Different percentages of FA and SF also affected on segregation resistance. The higher ratio of FA and SF the lower the segregation index of SCC. The values of segregation match with The European Specification of SCC, 2005.
7. The mechanical properties of SCC are higher for all specimens cured in water than those cured in air at age of 28 days.

REFERENCES

[1] A. Ma'aruf, S.I. Abba, and M.M. Nuruddeen," Self-compacting concrete – a Review," International Journal of Innovative Technology and Exploring Engineering, vol. 6, pp. 1-7, March 2017.
[2] F.A. Mustapha , A. Sulaiman, R.N. Mohamed, and S.A. Umara," The effect of fly ash and silica fume on self-compacting highperformance concrete," Materials Today: Proceedings, vol. 39, pp. 965-969, 2021.
[3] R. Suriya, and K. Soundhirarajan," Effects on cement blends of self compacting concrete containing metakaoline and fly ash," International Journal of Civil Engineering, vol. 4, pp. 45-47, February 2017.
[4] D. Sathya Narayana, A. Pavani, and N.V.H. Reddy," Mechanical properties of self compacting concrete with partial replacement of rice husk ash," International Journal of Trend in Scientific Research and Development, vol. 1, pp. 504-512, 2017.
[5] J.H. Bhat," Mechanical behaviour of self compacting concrete: Effect of wood ash and coal ash as partial cement replacement," Materials Today: Proceedings, vol. 42 , pp. 1470–1476, 2021.
[6] R.V. Kumar, B.K. Chaitanya, L.N.K. Sai Madupu, and N.V.S. Kumar," Evaluation of mechanical and flow properties of Crimpled steel fiber in self compacting concrete," Materials Today: Proceedings, pp.1-6, 2021.
[7] I. gull, and M.A. Tantray," Characteristic influence of carbon fibers on fresh state, mechanical properties and microstructure of carbon fiber based self compacting concrete," Materials Today: Proceedings, vol. 38 , pp. 3181–3189, 2021.
[8] N. Gupta, R. Siddique, and R. Belarbi," Sustainable and greener self-compacting concrete incorporating industrial by-products: a review," Journal of Cleaner Production, vol. 284 , 2021.
[9] R. Prakash, S.N. Raman, N. Divyah, C. Subramanian, C. Vijayaprabha, and S. Praveenkumar," Fresh and mechanical characteristics of roselle fibre reinforced self-compacting concrete incorporating fly ash and metakaolin," Construction and Building Materials, vol. 290, 2021.
[10] M. Omrane, and M. Rabehi," Effect of natural pozzolan and recycled concrete aggregates on thermal and physico-mechanical characteristics of self-compacting concrete," Construction and Building Materials, vol. 247 , 2020.
[11] P. Ramanathan, I. Baskar, P. Muthupriya, and R. Venkatasubramani," Performance of self-compacting concrete containing different mineral admixtures," Journal of Civil Engineering, vol. 17, pp. 465-472, 2013.
[12] The European Guidelines for Self-Compacting Concrete Specification, Production and Use, 2005.
[13] ISO 4012 Concrete-Determination of Compressive Strength of Test Specimens.
[14] ISO 1920 Concrete Tests-Dimensions, Tolerances and Applicability of Test Specimens.
[15] ISO 4013 Determination of Flexural Strength of Test Specimens.
[16] BS-1881 Testing Concrete, Part 117 Method of Determination of Tensile Splitting Strength.