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Abrasion resistance and mechanical properties of self-compacting concrete with different dosages of fly ash/silica fume

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In this study, nine different types of concrete were adopted: vibrated traditional concrete (VTC) with low slump (68 mm) and eight types of self-compacting concrete (SCC) in which cement was partially replaced by four kinds of replacements (25%, 30%, 35% and 40%) of class F fly ash (FA) and by four kinds of replacements (5%, 10%, 15% and 20%) of silica fume (SF). The main objective of this research was to evaluate the effect of different types and dosages of mineral additions on the mechanical properties and abrasion resistance of SCC. Compressive, splitting tensile strength and UPV tests were conducted for the ages of 3, 28 and 130 days whilst the modulus of elasticity and the abrasion resistance tests were performed for 28 days. Consequently, it was found that although the compressive and tensile strength and the UPV values of SCC specimens were higher generally than those of VTC specimens for all curing ages, the compressive strength and the UPV values of SCC specimens decreased for 3 days when FA and SF content increased. The modulus of elasticity of SCC specimens with SF in general increased with an increase in SF content whilst the modulus of elasticity decreased with an increase in FA content. Moreover, it was concluded that increasing SF content more improved the abrasion resistance of SCC compared to FA whilst the abrasion resistance of all SCC specimens was higher than that of VTC. On the other hand, there was a strong correlation, which is not dependent on the mineral admixture type and content, between the wear loss with compressive strength and the elasticity modulus for SCC specimens.

Keywords: Self-compacting concrete, Silica fume, Fly ash, Mechanical properties, Abrasion resistance

Concrete performance is commonly evaluated with respect to engineering or mechanical properties such as compressive strength and modulus of elasticity, and less frequently, tensile strength, shrinkage and creep. As regards the durability of concrete, other properties are used, such as carbonation and chloride penetration resistance, and less frequently, water absorption and air/oxygen permeability whilst abrasion resistance is rarely cited. However, concrete abrasion resistance is particularly important in pavements, floors, hydraulic structures such as tunnels and dam spillways or other surfaces upon which friction forces are applied due to relative motion between the surfaces and moving objects. Finally, abrasion resistance is relevant to any use of concrete where rubbing, scraping, skidding or sliding of objects on the surface usually occur[1].

The abrasion-erosion resistance of concrete is markedly influenced by factors like, aggregate property and dosage, concrete strength, mixture proportion, the use of supplementary cementitious materials, fiber addition, curing conditions and surface finishing[2-8]. The most of these properties are made possible by reducing porosity in homogeneity, microcracks in concrete and in the interface between cement paste and aggregate and increase the binder content. This can be achieved by using super plasticizers and supplementary cementing materials such as fly ash, silica fume, granulated blast furnace slag and natural pozzolan[9,10]. Because, high-strength concrete mixtures have a high cement content that enhances the heat of hydration and may cause increased shrinkage that results in a potential of cracking and low durability. To increase the service life of the hydraulic structures and keep them in a safe and reliable state as long as possible, hydraulic concrete must have high durability. Therefore, in most mixtures, cement is replaced partly with supplementary cementitious materials such as fly ash to reduce the hydration heat and increase the durability[11-15]. SCC mixes always contain a powerful superplasticizer and often use a large quantity of

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*Corresponding author (E-mail: kturk@harran.edu.tr) supplementary cementing materials. The superplasticizer is necessary for producing a highly fluid concrete mix, while the powder materials are required to maintain sufficient stability/cohesion of the mix, hence reducing bleeding, segregation and settlement. Moreover, as fine materials are substantial constituents of SCC, the replacement of mineral admixtures with cement in SCC contributes significantly to its fresh and hardened properties as well as to reducing its cost[16,17].

Some researchers[3,12,18-20] have studied the influence of Class F fly ash on the abrasion resistance of vibrated traditional concrete. Liu[3] reported that the abrasion of concrete with or without 25% fly ash was similar up to 36 h of abrasion testing. But after 72 h of testing, the fly ash concrete had about 25% more abrasion than control concrete. Concrete containing Class C fly ash exhibited better abrasion resistance than both concrete without fly ash and concretes containing Class F fly ash[12]. The abrasion resistance of fly ash concrete was found to be similar to normal concrete[18]. Siddique[19] investigated the influence of replacing cement with 0-40% Class F fly ash on the abrasion resistance of concrete up to the age of 365 days. Test results indicated that abrasion resistance of concrete mixtures increased with the increase in fly ash content. On the other hand, the presence of fly ash at high levels (50%) of cement replacement was found to decrease the abrasion resistance at all ages in comparison to concrete made without fly ash. Tsong *et al.*[20] found that fly ash concrete with up to 15% cement replacement exhibited the abrasion-erosion resistance similar to concrete without fly ash at 28 and 91 days. However, the abrasion-erosion resistances of fly ash concrete with 20%, 25% and 30% cement replacements were lower than that of the non-fly ash concrete. Class F fly ash concrete with up to 15% cement replacement was acceptable for structural applications of abrasion-erosion resistance.

As for the effect of SF on the wear resistance of vibrated traditional concrete, Ghafoori and Diawara[21] investigated the abrasion resistance of concrete incorporating four percentages of fine aggregate replacement (5%, 10%, 15%, and 20%) with silica fume. They concluded that the resistance to wear of concrete containing silica fume as a fine aggregate replacement was consistently better with increasing amounts of silica fume up to 10%. Zeng-Qiang and Chung[1] found the abrasion resistance of mortar to be significantly improved by the addition of latex, and further improved by an addition of short carbon fibres. Both effects relate to the increase in tensile strength. The abrasion resistance was also improved by the addition of silica fume, due to the increase in tensile modulus. The abrasion resistance was better for mortar with silica fume than mortar with latex, but was worse for mortar with silica fume than for mortar with latex and carbon fibres. Lui[22] reported that the abrasion resistance increase with respect to the increase of silica fume addition. For concrete with surface crack width of 1 mm and water flow impinging directly on the crack, the gains in abrasion rate were nearly 13% and 25%, respectively, more than that of the reference mixture.

SCC is a new kind of concrete that combines a high flowability and a high segregation resistance obtained by a large amount of fine particles and the use of superplasticizers. As this kind of concrete can be placed without any compaction, some health risks as well as environmental problems can be avoided. Moreover, strength and durability (such as abrasion resistance) problems related to insufficient compaction of the concrete can be avoided. The main objective of this study was to systematically assess the mechanical properties and the abrasion resistance by investigating the compressive, splitting tensile strength, ultrasound pulse velocity and the wear loss of SCC mixes containing different type and dosages of mineral additions in comparison with vibrated traditional concrete.

Experimental Procedure

Materials

In this study, ASTM Type I Portland cement (PC 42.5) conforming to TS EN 197-1 was used whilst F class FA and SF were added into the mixture in the replacement of PC as mineral additions. The chemical composition and physical properties of PC, FA and SF are given in Table 1. Natural sand with a fineness modulus of 3.05 and gravel with a nominal maximum size of 20 mm were used as the aggregates for all mixtures. The relative density values for 0-7, 7-15 and 15-20 mm were 2.63, 2.64 and 2.66 g/cm^3, and absorption rates were 1.57%, 1.0% and 0.7%, respectively. Moreover, melamine sulfonate based polymer for VTC and modified polycarboxylates based polymer for SCC, which had specific gravity of 1.22 and 1.06, respectively, were used as the chemical admixtures.

Mixture proportions

Assuming saturated-dry surface conditions for the aggregates, the mix proportions for vibrated traditional and self-compacting concretes are given in Table 2. While VTC mix was prepared by only ordinary Portland cement as binder, SCC mixes were prepared by replacing cement at 5% intervals from 25% to 40% with FA and from 5% to 20% with SF on mass-for-mass basis. A water-cementitious material ratio (w/c) of ≈0.38 was adopted for all mixes. High-range water reducing chemical admixture (HRWRA) dosages in a range of 1.35% and 1.78% for SCC with FA and SF, respectively, was selected to maintain slump flows at 705 ± 4 mm whilst water reducer admixture (WRA) dosage in a range of 1.57% for VTC with low slump of 68 mm was selected to obtain as high strength as possible. In order to identify the SCC mixes, SCC with FA/SF is designated as 'FA' and 'SF', respectively. The numerical value after 'FA' and 'SF' represents weight percentage of FA and SF incorporated as cement replacement.

Table 1 — Chemical analysis and physical properties of PC, FA and SF (%)

Component	PC (%)	FA (%)	SF (%)
SiO_2	20.2	58.82	91
Al_2O_3	5.8	19.65	0.58
Fe_2O_3	3.23	10.67	0.24
CaO	64.1	2.18	0.71
MgO	-	3.92	0.33
SO_3	2.66	0.48	-
Chloride (Cl^-)	0.006	-	-
LOI	2.58	0.91	1.84
Specific gravity	3.1	2.08	2.2
Specific surface area (cm^2/g)	3484	3812	96.5%<45 μm
Compressive strength (MPa)			
2 days	23.7	-	-
7 days	44.0	-	-
28 days	55.2	-	-

Workability tests for concretes and casting

While workability of VTC mix was measured according to ASTM C143 standard[23] using slump test, mix designs for SCC mixes were developed by means of trial mixes based on guidance given in EFNARC[24]. For SCC mixes, slump flow, T_{50cm}, L-box and sieve segregation resistance tests described in EFNARC were carried out. The fresh properties of the nine different concretes are given in Table 3. The results obtained from these tests showed that SCC mixes had in general good flow, filling and passing ability as well as segregation resistance except for SCC mixtures with FA25, SF15 and SF20. All VTC specimens were cast on a vibrating table to ensure optimum compaction, whilst the SCC specimens were cast without any vibration.

Table 2 — Mix proportions (kg/m^3)

Mixtures	VTC	SCC with FA				SCC with SF			
		FA25	FA30	FA35	FA40	SF5	SF10	SF15	SF20
w/cm[a]	0.39	0.39	0.38	0.38	0.38	0.36	0.38	0.40	0.40
Cementitious mater	350	500	500	500	500	450	450	450	450
Cement	350	375	350	325	300	427.5	405	382.5	360
FA	-	125	150	175	200	-	-	-	-
SF	-	-	-	-	-	22.5	45	67.5	90
Aggregate sizes (mm)									
0-7	800	910	910	910	910	990	990	990	990
7-15	500	450	450	450	450	450	450	450	450
15-20	650	285	285	285	285	285	285	285	285
WRA	5.50	-	-	-	-	-	-	-	-
HRWRA	-	6.75	6.75	6.75	6.75	8.00	8.00	8.00	8.00

[a] w/cm is water to cementitious materials (PC+FA or SF) ratio

Table 3 — Properties of fresh concretes

Mixtures	VTC	SCC with FA				SCC with SF			
		FA25	FA30	FA35	FA40	SF5	SF10	SF15	SF20
Slump (mm)	68	709[b]	702[b]	705[b]	701[b]	707[b]	701[b]	708[b]	707[b]
T_{50cm} (s)	-	2.44	2.56	3.00	2.89	2.30	1.80	1.20	1.00
L-box; H_2/H_1	-	0.910	0.943	0.953	0.959	0.865	0.876	0.888	0.890
Segregation (%)	-	18.4	15.8	15.2	14.4	15.3	17.9	19.8	22.0

[b] Slump Flow (mm)

In this study, 150 mm concrete cubes for the compressive strength and UPV tests, 150 mm × 300 mm concrete cylinders for the splitting tensile strength test, ϕ 100 × 200 mm concrete cylinders for the modulus of elasticity test and 71 mm concrete cubes for the wear resistance test were cast. In the following day of casting, all specimens were de-moulded and immersed in water at 20°C. The specimens used for the compressive strength, splitting tensile strength and UPV tests were cured for 3, 28, 90 days whilst and the modulus of elasticity and the abrasion resistance tests were conducted only for 28 days. Three specimens from each mix were used to determine the mechanical properties whilst five specimens from each mix were used to determine the abrasion resistance of mixtures investigated.

Testing

Compressive, splitting tensile strength and ultrasound pulse velocity tests were performed according to ASTM C39[25], ASTM C496[26] and ASTM C597[27], respectively whilst the modulus of elasticity test was conducted according to ASTM C469[28]. Cube samples of 71±1.5 mm were used for the determination of abrasion resistance according to Turkish standard specifications TS 699-1987. Although this standard is highly recommended for the wear of natural stones, this standard is applied on concrete specimens as an alternative of ASTM C779[29]. This method was used by many researchers and reliable results were obtained[30-32]. In compliance with TS 699, the abrasion system had a steel disc, which had a diameter of 750 mm and rotating speed of 30±1 cycle/min, a counter and a lever, which could apply 300±3 N on the specimens. Abrasion test apparatus is shown in Fig. 1. In the test procedure, 20±0.5 g of wear dust was spread on the disc, the specimens were then placed, the load was applied to the specimen and the disc was rotated for four periods, while a period was equal to 22 cycles. After that, the surfaces of the disc and the sample were cleaned by the brush. The above-mentioned procedure repeated for 20 periods (totally 440 cycles) by rotating the sample 90° in each period. The volume decrease was measured in cm^3/cm^2 due to wear. Abrasive dust used in this test was corundum (crystalline Al_2O_3).

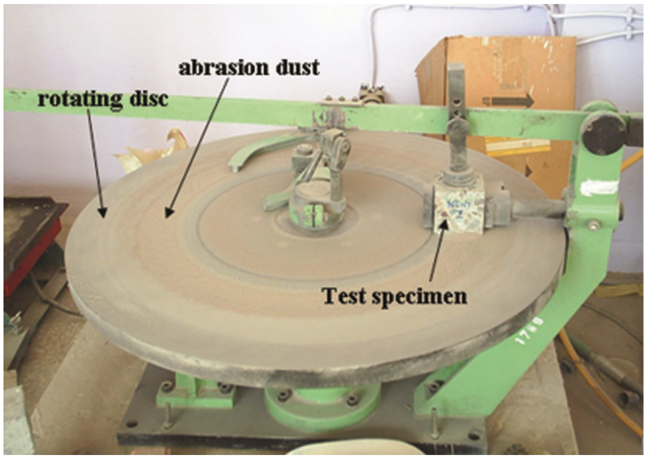

Fig. 1 – Abrasion test apparatus as specified in TS 699

Results and Discussion

Compressive strength

Compressive strength results of VTC and SCC specimens with FA/SF for 3, 28 and 130 days are presented in Fig. 2a and b, respectively. It can be observed from these figures that all SCC specimens had higher compressive strength, compared to VTC specimens. Because, if SCC is properly proportioned, produced and placed, it is generally more compact and homogeneous than equivalent vibrated traditional concrete, hence leading to improved strength and durability performance of concrete structures when made with SCC[33]. SCC with SF5 had the highest compressive strength with 36.15 MPa followed by FA25 with 27.66 MPa for 3 days indicating that SF due to its highly reactive nature may provide significant amounts of calcium silicate hydrates (C-S-H) at an early age. However, the compressive strength of SCC specimens decreased with an increase in both FA and SF content for 3 days. Because at normal temperatures, the pozzolanic reaction is slow to start and it does not progress to any significant degree until several weeks after the start of hydration[34,35]. Moreover, the highest compressive strength was obtained from the specimens of SCC with SF in all mixes investigated for all curing ages whilst SCC with SF15 had the highest compressive strength with 67.95 and 73.87 MPa for 28 days and 130 days, respectively. Hereby, it can be said that as SF is a very reactive pozzolan and appears to be effective filler, the enhancing effect of SF on concrete compressive strength is due to its ability to improve the bond between the aggregate particles and the paste phase[36-38]. On the other hand, it is seen from Fig. 2a that FA25 had the highest compressive strength with 27.66 and 49.39 MPa at 3 and 28 days, respectively, whilst FA40 had the highest compressive strength with 58.11 MPa followed by FA35, FA30, FA25 and VTC at the periods of 130 days. Similar trend was obtained in another study performed by Khatib[39] who found that SCC containing 40% FA shows higher 56 days strength than that of the other FA mixes including the 20% FA mix. Also, FA is believed to be inert at this very early stage. In addition to all these, there was in general an increase in the compressive

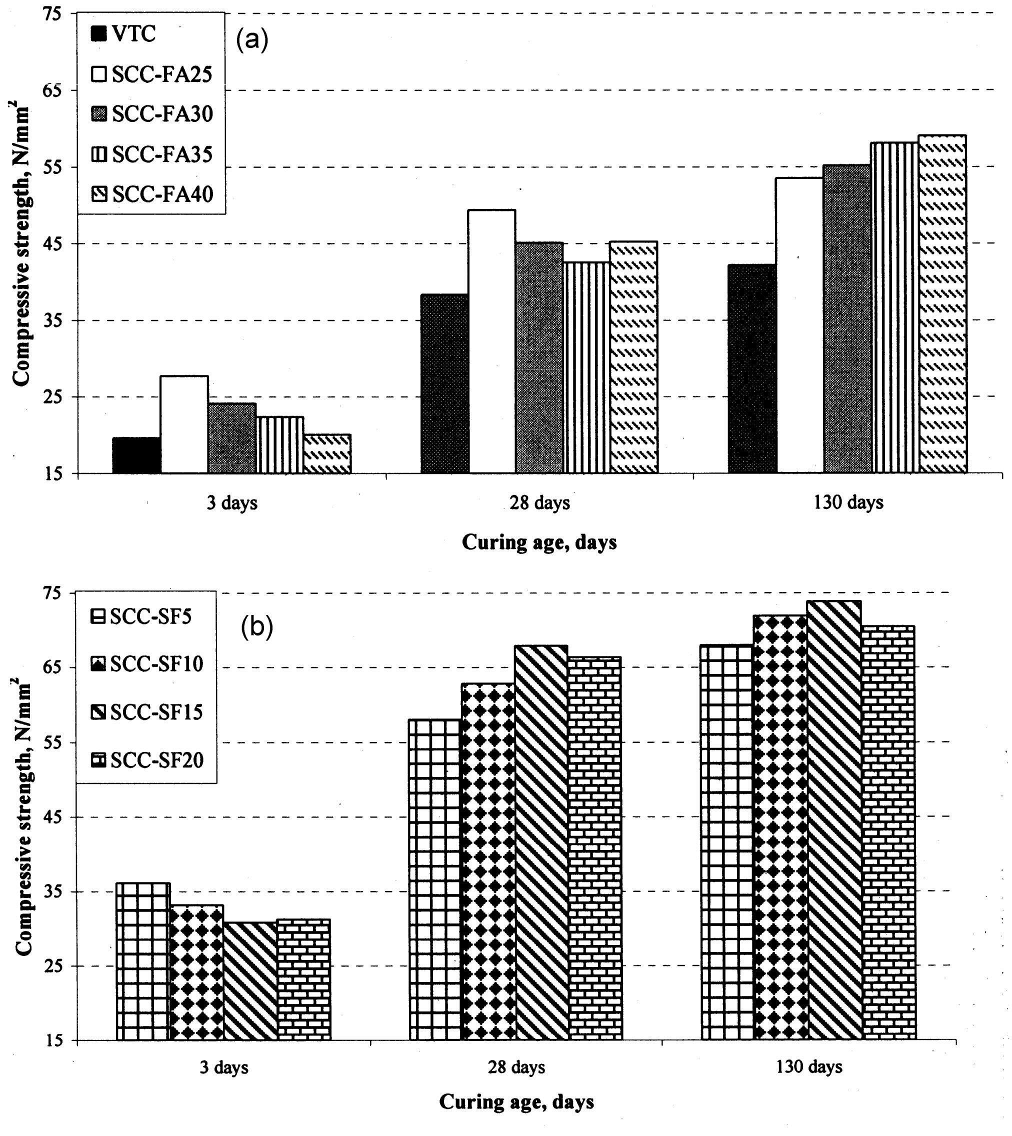

Fig. 2 – Compressive strength of concretes for 3, 28 and 130 days (a) VTC and SCC with FA and (b) SCC with SF

strength values of SCC specimens with increase in both FA and SF content for periods of 130 days. This increase in strength can be attributed the densification of the paste structure due to the pozzolanic action between pozzolans (FA and SF) and CH released as result of hydration of cement[40]. However, the compressive strength of SCC specimens with SF20 did not increased with increase in SF content compared to SCC specimens with SF15. The w/c ratio of both mixtures was same with 0.40 although SCC with SF20 mixture had higher the specific surface area than SF15 mixture. On account of this, SF induced retarding of cement hydration and prolonging the dormant period, due to low w/c ratio[34] and this may prevent the reduction of capillary porosity during hydration.

Splitting tensile strength

Test results of the splitting tensile strength of VTC and SCC specimens with FA/SF are shown in Fig. 3a and b. As can be expected, the splitting tensile strength of VTC and SCC specimens continued to increase with age. The splitting tensile strength of SCC specimens with SF was the highest followed by SCC specimens with FA and VTC specimens for all curing ages. At curing ages of 3 days, the splitting tensile strength of SCC specimens with FA decreased with an increase in the FA content whilst the splitting

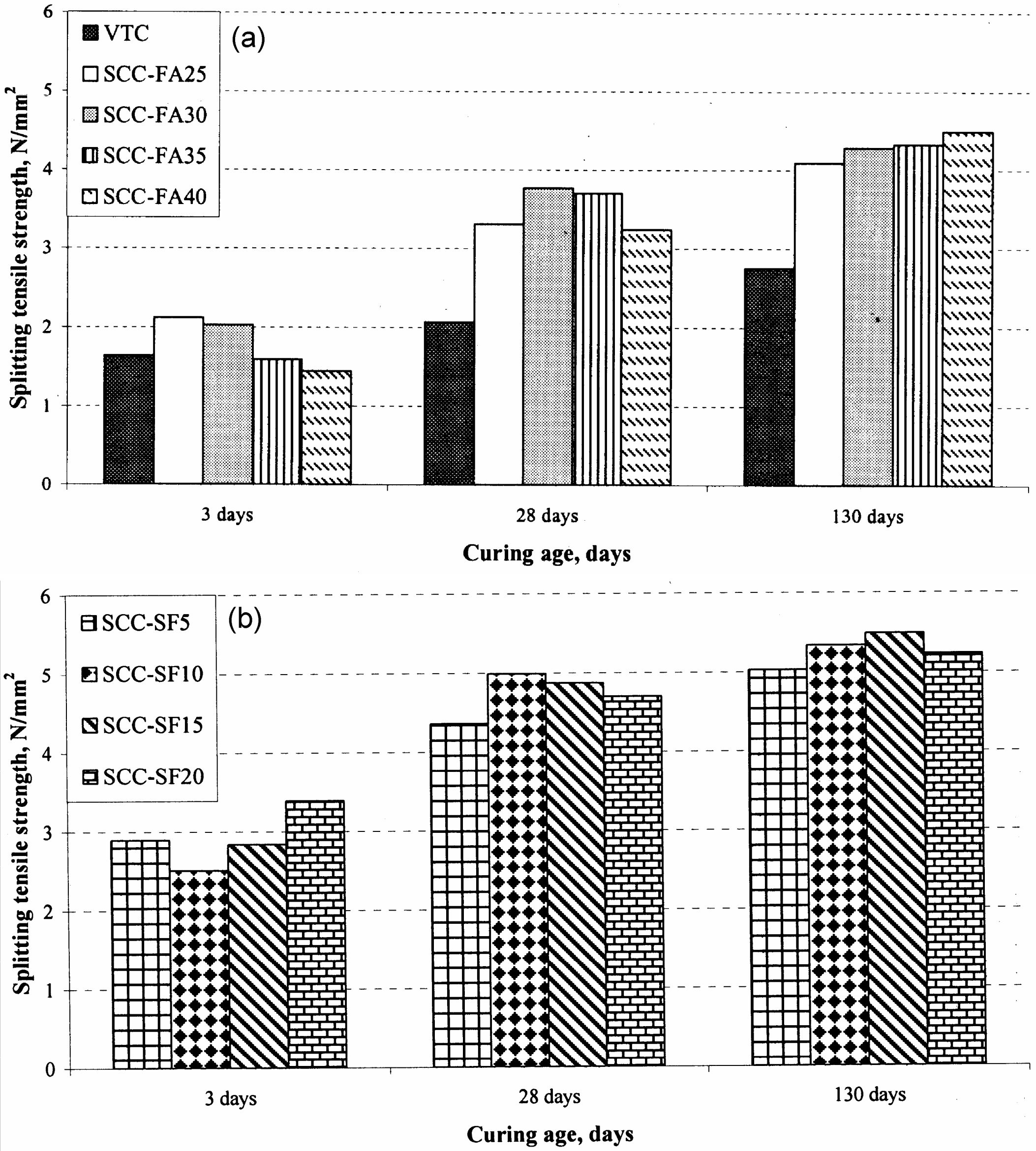

Fig. 3 – Splitting tensile strength of concretes for 3, 28 and 130 days (a) VTC and SCC with FA and (b) SCC with SF

tensile strength of SCC specimens with SF in general increased with an increase in the SF content. The SF may provide significant amounts of C-S-H due to its higher pozzolanic activity at early age. There was not significant difference between the values of the splitting tensile strength of SCC specimens with FA/SF for 28 and 130 days. At the curing ages of 130 days, an increase in the FA and SF content in general led to an increase in the splitting tensile strength. Furthermore, difference between the values of the splitting tensile strength of SCC and VTC specimens increased at the curing ages of 130 days. These may be attributed to the pozzolanic reaction for forming C-S-H gel. On the other hand, it can be seen that the increase in compressive strength will be more than that of tensile strength when FA/SF content increased. This may be explained with the effect of the unreacted FA/SF particles on the tensile properties as the bond between aggregate and the blended paste will be affected more by the splitting tensile test[41].

Ultrasound pulse velocity

The effect of fly ash and silica fume on the UPV values of VTC and SCC specimens at the curing periods of 3, 28 and 130 days is shown in Fig. 4a and b. Although the UPV values of SCC specimens with FA/SF in general decreased for all curing periods when the FA/SF content in SCC mixtures increased, the UPV values of SCC specimens with FA were the highest as compared VTC and SCC with SF for all curing ages due to the filling and packing capacity of FA particles[32]. However, SCC specimens with SF had

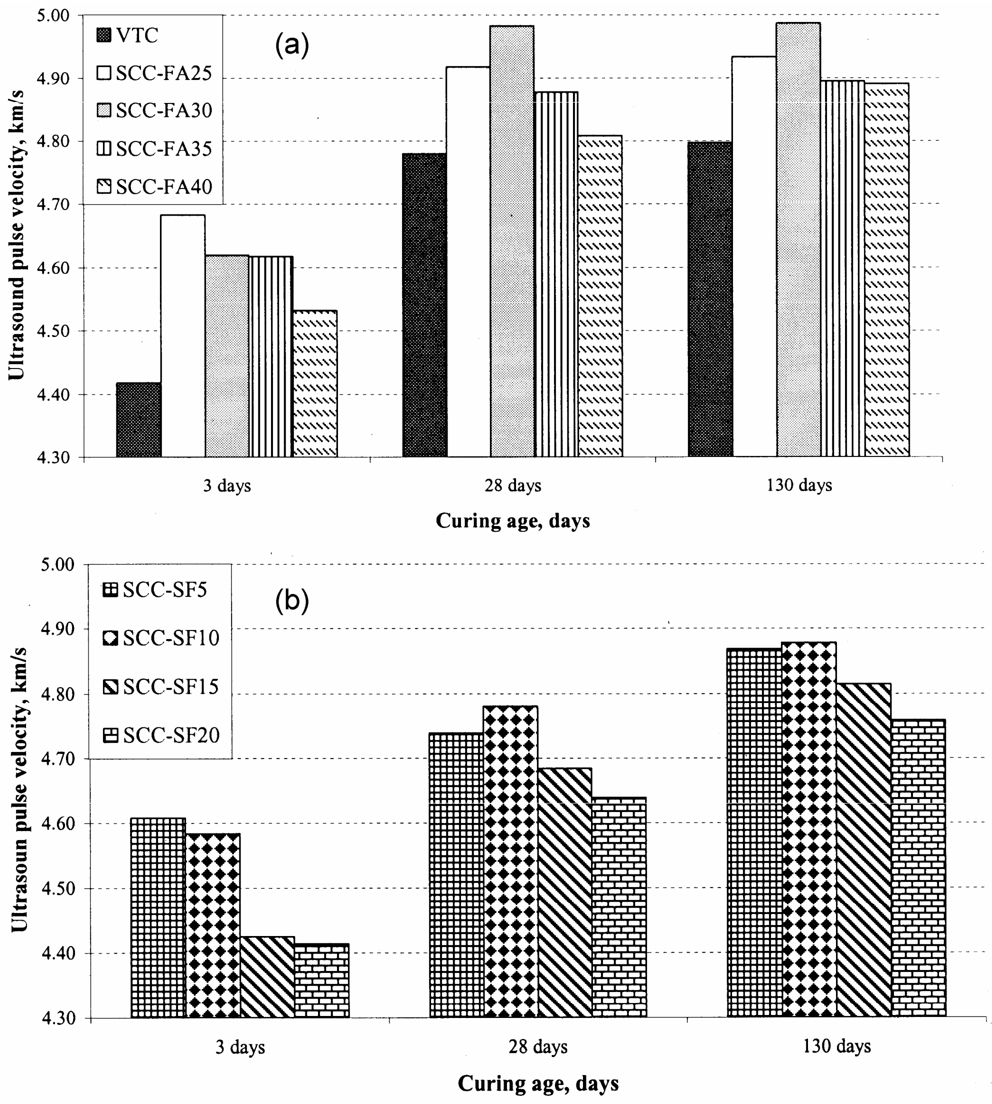

Fig. 4 – Ultrasound pulse velocity of concretes for 3, 28 and 130 days (a) VTC and SCC with FA and (b) SCC with SF

higher UPV values than VTC specimens for 3 and 130 days except for SCC with SF20 whilst there was adverse condition for 28 days. The UPV values of SCC with FA30 and SF10 were in general higher than those of other SCC specimens except for the curing age of 3 days when it was only examined SCC specimens. Moreover, it can be said that at the curing periods of 130 days there were not important difference between the UPV values of SCC specimens. Because an increase in the curing age caused the formation of further amount C-S-H gel and thus a denser structure formed in cement paste. However, the UPV values of SCC specimens with SF in general decreased for all curing ages whilst the SF replacement levels in SCC mixes were varied from 5 to 20% at 5% intervals. It can be emphasized from here that the mixture containing lower SF content is denser than the mixture containing higher SF content at the same water/binder ratio, even though their strength is to close each other. Similar results were obtained by Hamid *et al.*[42] for high performance concrete with SF.

The modulus of elasticity

The modulus of elasticity results of VTC and SCC specimens with FA/SF for 28 days are presented in Fig. 5. It can be seen from here that SCC specimens with SF had the highest elasticity modulus followed by NC specimens and SCC specimens with FA. The modulus of elasticity of SCC specimens with SF in general increased with an increase in the SF content whilst SCC specimens with SF15 had the highest elasticity modulus in all specimens. However, the modulus of elasticity of SCC with FA decreased with an increase in the FA content whilst SCC specimens with FA25 had the highest elasticity modulus in SCC specimens with FA. Moreover, it was emphasized from here that the use of FA as mineral admixture in SCC caused the reduction of the modulus of elasticity of SCC compared to VTC.

In addition to these, it was seen from Fig. 6a and b that the correlation between the values of compressive strength and those of elasticity modulus for SCC specimens containing both FA and SF was very good with R^2 values over 0.90.

Abrasion resistance

The average results of the compressive strength, splitting tensile strength, the elasticity modulus and wear loss values for 28 days as well as the coefficient of variation for vibrated traditional and self-compacting concretes were given in Table 4. It is seen from test results in Table 4 that SCC specimens with FA/SF had less depth of wear compared to VTC specimens whilst the abrasion resistance of SCC specimens with SF was highest in all mixtures. Also, the abrasion resistance was found to increase with the increase of the compressive strength and the elasticity modulus but an increase in the abrasion resistance of SCC specimens did not show much dependence on the tensile strength. The presence of increasing amounts of SF improved the abrasion resistance because the depth of wear decreased with an increase in the SF content. But improvement in the abrasion

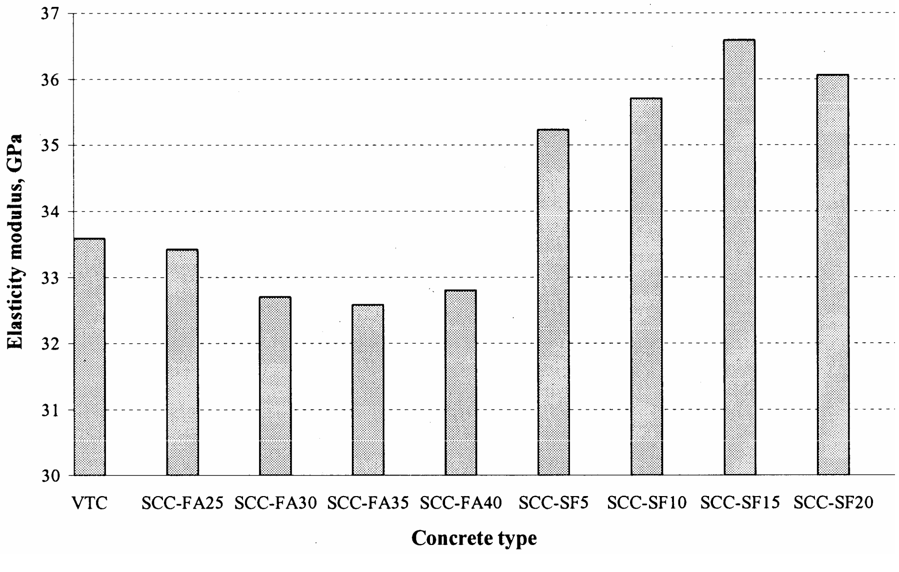

Fig. 5 – The modulus of elasticity of VTC and SCC specimens for 28 days

resistance for SCC with SF20 did not continue due to low water-cement ratio as stated by some researchers[34,43]. In addition, the abrasion resistance of SCC specimens decreased with increasing FA content. This reduction for specimens with FA may be attributed mainly to its low reactivity. SCC specimens with SF15 had the highest abrasion resistance followed by SCC specimens with SF20, SF10, SF5, FA25, FA40, FA30, FA35 and VTC specimens. It was seen that all SCC specimens with SF had more improved abrasion resistance with an increase in SF content compared to SCC with FA because SF improves the bond between the aggregate particles and the paste phase due to its chemical and physical effects on the cement hydration process. A possible explanation for that is that SF underwent rapid dissolution in the calcium hydroxide solution and formed a calcium poor silica rich layer on the SF particles in a matter of minutes, thus serving the formation of conventional C-S-H gel as a substrate[44]. These results were also obtained for vibrated traditional concretes with FA/SF by other researhers[45-47]. Yazici and İnan[45] emphasized that the wear resistance of high strength concrete can be estimated from strength results. Siddique[46] reported that wear resistance of concrete mixtures with FA was lower

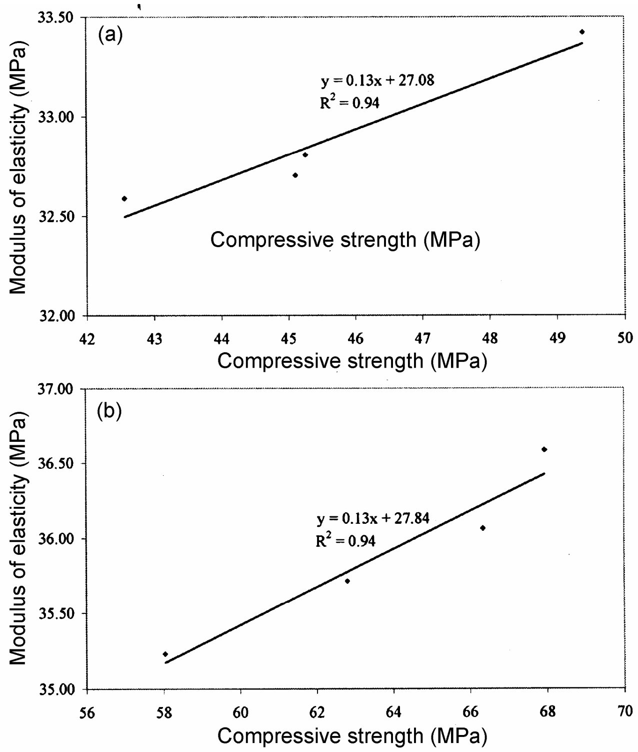

Fig. 6 – Relationship between 28-day compressive strength and the modulus of elasticity (a) SCC with FA and (b) SCC with SF

Table 4 — The mechanical properties and wear loss results of concrete mixtures for 28 days

Mixture code	Statistical values	Elasticity modulus (GPa)	Compressive strength (MPa)	Splitting tensile strength (MPa)	Loss on wear (cm^3/50cm^2)
VTC	Average	33.59	38.32	2.07	11.03
	S.D.	3.10	1.08	0.10	0.20
SCC-FA25	Average	33.42	49.39	3.31	9.80
	S.D.	1.74	2.44	0.33	1.17
SCC-FA30	Average	32.70	45.11	3.77	10.14
	S.D.	1.09	2.12	0.60	0.84
SCC-FA35	Average	32.59	42.56	3.70	10.82
	S.D.	0.83	1.54	0.38	0.56
SCC-FA40	Average	32.81	45.26	3.24	11.33
	S.D.	1.36	1.91	0.28	1.23
SCC-SF5	Average	35.23	58.04	4.36	8.93
	S.D.	2.10	0.56	0.56	0.68
SCC-SF10	Average	35.71	62.81	4.99	8.36
	S.D.	1.42	0.84	0.18	1.04
SCC-SF15	Average	36.54	67.95	4.87	7.28
	S.D.	1.14	1.72	0.36	0.60
SCC-SF20	Average	36.06	66.35	4.70	7.74
	S.D.	1.83	1.87	0.14	0.58

S.D.: Standard deviation

than that of control mixture and decreases with the increase in FA content. Moreover, Naik *et al.*[47] found that high-volume fly ash concrete systems had lower wear resistance values compared to no-fly ash concrete.

Relationship between abrasion resistance and mechanical properties

The relationship between the values of compressive strength, splitting tensile strength, ultrasound pulse velocity and the modulus of elasticity with that of loss on wear was shown in Figs 7-10, respectively. Each of these figures includes equation and correlation coefficient. The best fit the data is a power relationship in the form of $y = ab^{-x}$ with R^2 values of 0.95 and 0.94 for the elasticity modulus and the compressive strength values, respectively, whilst a power relationship seems to be good fit the data R^2 values of 0.79 for splitting tensile strength values. However, a power relationship in the form of $y = ab^{x}$ does not seem to be good fit the data with R^2 values of 0.56 for UPV values.

The high value of correlation coefficient indicates that the wear loss has a strong relationship with the elasticity modulus and the compressive strength. This relationship seems to be unaffected by the mineral addition type and content for SCC specimens. The abrasion resistance of SCC with FA/SF with the compressive strength ranging from approximately 40 to 70 MPa was investigated. As seen from Fig. 7, 8 and 10, loss on wear values of SCC specimens decreased as the compressive strength, the tensile strength and the elasticity modulus increased, regardless of mineral admixture type and content. These results for the compressive and tensile strength consistent with the findings of other researchers for fly ash concretes[6,19,20]. Consequently, an increase in compressive and splitting tensile strength led to in general an increase in abrasion resistance of SCC specimens that same results found for different concretes by another studies[20,40,45,48]. However, there was an inverse correlation between the values of UPV and wear loss (see Fig. 9). Because, the UPV values of SCC with FA/SF generally decreased with increase

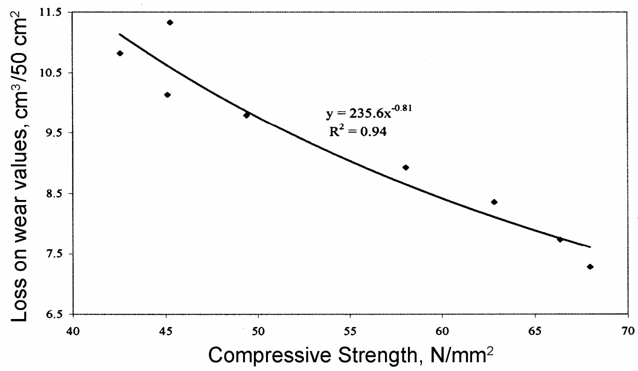

Fig. 7 – Relationship between 28-day compressive strength and loss on wear of SCC with FA/SF

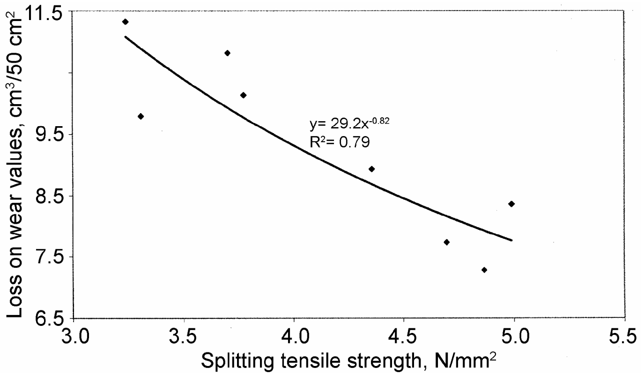

Fig. 8 – Relationship between 28-day splitting tensile strength and loss on wear of SCC with FA/SF

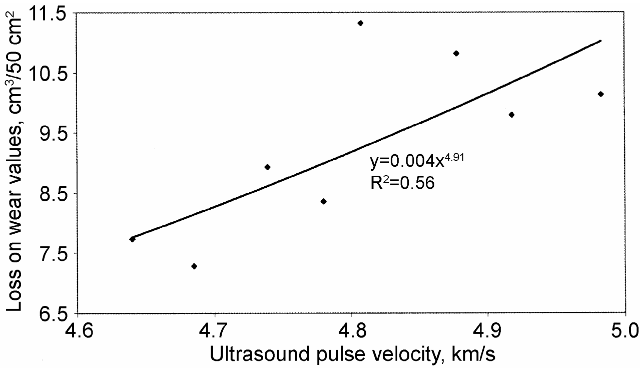

Fig. 9 – Relationship between 28-day UPV and loss on wear values of SCC with FA/SF

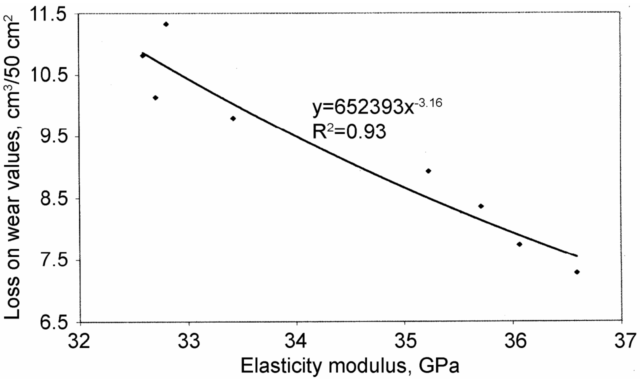

Fig. 10 – Relationship between 28-day the elasticity modulus and loss on wear values of SCC with FA/SF

in both FA and SF content for 28 days indicating that the pozzolanic reactions did not sufficiently develop in 28-day of the curing time due to increasing in mineral admixture content, hence leading to a less dense internal-structure.

Conclusions

The abrasion resistance and mechanical properties of VTC without mineral addition and SCC made of various additions of F class FA/SF was examined as a partial replacement of cement. Based on the results, the following conclusions can be drawn:

(i) SCC specimens with SF/FA had in general higher the compressive, tensile strength and the UPV values than VTC specimens for all curing ages whilst the compressive strength and the UPV values of SCC specimens decreased with an increase in both FA and SF content for 3 days. SCC with SF15 had the highest compressive and tensile strength with 73.87 and 5.489 MPa for 130 days, respectively. SCC specimens with FA had in general the highest UPV values compared to VTC and SCC specimens with SF for all curing ages. Moreover, the modulus of elasticity of SCC specimens with SF in general increased with an increase in SF content whilst the modulus of elasticity decreased with an increase in FA content.

(ii) SCC specimens with FA/SF had less depth of wear compared to VTC specimens whilst the abrasion resistance of SCC specimens with SF was highest in all mixtures. The presence of increasing amounts of SF improved the abrasion resistance except for SF20 due to inadequate water-to-cement ratio. However, the abrasion resistance of SCC specimens with FA decreased when FA content increased from 25 to 35% at 5% intervals. It can be emphasized that SCC specimens with SF had more improved abrasion resistance with an increase in SF content compared to specimens with FA.

(iii) The high correlation coefficient with over 0.90 indicated that there was a strong relationship between the wear loss with the compressive strength and the elasticity modulus of SCC with FA/SF. Furthermore, it was concluded that this relationships seems to be unaffected by the mineral addition type and content for SCC specimens. An increase in compressive strength, splitting tensile strength and the elasticity modulus led to in general an increase in abrasion resistance of SCC specimens. However, there was an inverse correlation between the values of wear loss and UPV. Because, the UPV values of SCC with FA/SF generally decreased with increase in both FA and SF content for 28 days.

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