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Airfield self-consolidating concrete pavements (ASCCP): Mechanical and durability properties

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HIGHLIGHTS

- SCC mixtures for air field concrete pavements (ASCCP) designed and studied.
- Mineral/chemical admixtures effects on mechanical/transport properties investigated.
- Freeze/thaw durability factor of SCC mixtures analyzed.
- Abrasion resistance and impact strength limits proposed for ASCCP.
- Visual inspection studies conducted for freeze/thaw distress related with ASCCP.

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ABSTRACT

This paper investigates the mechanical, transport properties and freeze/thaw durability of self-consolidating concrete mixtures used in airfield self-consolidating concrete pavement (ASCCP). ASCCP mixtures are made with mineral admixtures that include fly ash, silica fume, slag, metakaolin and air entraining chemical admixture (AEA). The results show that the use of metakaolin as the mineral admixture significantly improved the mechanical properties and durability factor, especially the freeze/thaw visual inspection parameters. The use of AEA produced similar improvements, but a decrease was observed in the mechanical properties. Abrasion resistance and impact strength limits were proposed for this study.

1. Introduction

Air transportation is one of the best modes of passenger and cargo transport and for security requirements. Downtime for rehabilitation and reconstruction concrete airfields significantly affects regional and trans-regional macroeconomics. The necessity of using a high performance concrete pavement for airfields is evident [1]. Airport pavement management systems (APMS) define15 types of defect that affect the concrete pavement condition index (PCI), 60% of which affect durability [2]. The resistance of concrete to freezing and thawing is one of the most important parameters influencing durability and results in 67% of durability defects in airfield concrete pavement [1–5].

Self-consolidating concrete (SCC) is a subset of high performance concrete (HPC) and has treatment and compatibility characteristics that differ from normal concrete (NC). The ability for high flow and consolidation under its own weight without vibration are major benefits of SCC and substantially decrease placement cost [6,7]. SCC could be an appropriate choice to increase the performance and consistency of concrete and is an economical engineering choice for concrete construction, especially concrete pavements [6,8]. Minimum allowable strength parameters can be achieved by changing the mix design of any type of concrete. The required high workability of concrete during casting and construction, especially for airfield concrete pavement, make SCC an appropriate choice.

The use of mineral admixtures is increasing globally because of its economic, environmental and performance advantages [6]. The durability of SCC differs from that of NC depending on mixture design and more research is needed in this area. The standards and regulations published by reliable institutions for airport concrete pavement are numerous and include those from the Federal Aviation Administration (FAA). The FAA has published

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requirements for the design and operation of concrete blend design. The best practices for airport Portland cement concrete pavement construction for rigid airport pavement are defined in the Innovative Pavement Research Foundation [9]. They stipulate that concrete should be designed to obtain minimum flexural strength of 4.1 MPa for airport pavement at28 days and an acceptable design modulus of rupture (DMR) for bending strength at 90 days. The permissible compressive strength must exceed 30.3 MPa [10]. Under normal conditions, the minimum required cement content for airfield concrete pavement is a function of the maximum size of aggregates (MSA). The MSA for this study was 19 mm, which requires a minimal cement content of 320 kg/m^3.Under freeze/thaw conditions, the value should be upgraded to 335 kg/m^3. The ratio of water to cementitious materials under these conditions should be 0.4–0.45, with the optimal ratio being 0.4 [9,10].

There have been no updated recommendations for construction and application of SCC for airfield concrete pavement. The present study examined the effects of mineral and chemical admixtures on the properties of SCC, including mechanical properties and the durability factor (DF). The critical condition of severe exposure was assumed for this study.

2. Experimental details

2.1. Materials

Locally available ordinary Portland cement type II conforming to ASTM C150 [11], limestone filler (LS), silica fume (SF), super-fine fly ash (FA), metakaolin (MK) and low activity ground granulated blast-furnace slag (LAGGBFS) were used as the cementitious materials. The chemical and physical properties of the cement and mineral admixtures are presented in Table 1.

Fine and coarse crushed limestone aggregate was obtained from local sources in southern Tehran province. The coarse aggregates had a saturated surface dry density of 2540 kg/m^3, maximum size of 19 mm and water absorption of 1.9%. Coarse and fine river sand were used as the fine aggregate with saturated surface dry densities of 2590 kg/m^3 and 2640 kg/m^3 respectively. The water absorption of these materials were 2.9%, and of 3.16% respectively. The particle size distributions of the solid materials are presented in Fig. 1.

The pozzolanic activity of the supplementary cementitious materials (SCMs) was evaluated by thermo-gravimetric (TG) analysis. This method is based on the thermal decomposition of crystalline calcium hydroxide ($Ca(OH)_2$) into calcium oxide and water at 400–500 °C. Sample preparation was performed by combining 50% SCM and 50% calcium hydroxide powder in the presence of sufficient water for a pozzolanic reaction after 9 d of curing. The calcium hydroxide consumption indicates the degree of pozzolanic activity, thus, the samples were analyzed by TG/DTA using an STA-449 C device (Jupiter model, Netzsch) in a static air atmosphere at a heating rate of 10 °C/min from 25 to 600 °C [12,13]. The results of TG analysis of SCMs are reported in Table 1. As seen, SF and LAGGBFS showed the highest and lowest activity, respectively. Table 1 also gives the pozzolanic activity of the mineral admixtures used in this study. The results show the lowest activity for LAGGBS and highest for SF.

A polycarboxylate-based high-range water reducing admixture (HRWRA) with a specific gravity of 1.1 ± 0.02 was incorporated into all mixtures while achieving the target slump flow of 700 ± 20 mm. An air-entraining admixture (AEA) with a specific gravity of 1.01 ± 0.02 was used to obtain a fresh air content of 6 ± 1%. Such amount of air content (entrained and entrapped) recommended for severe frost exposure [9,10] and maximum aggregate size of 19 mm. This anionic liquid agent has a pH of 8.5 ± 1 and a maximum chloride content of 500 ppm.

2.2. Mixtures proportions

Six SCC mixtures with a water/cementitious material ratio (w/cm) of 0.40 were prepared using binary or ternary binders. The proportions of the SCC mixtures are documented in Table 2. As seen, the total paste volume was kept constant at 380 l/m^3 for all SCC mixtures. This parameter is the sum of the volumes of the cementitious material, filler, water and total entrained and entrapped air content. The total cementitious material (binder) content was kept constant at 400 kg/m^3 to provide a relatively high volume fraction of fine material (paste volume of 350–400 l/m^3) that conforms to common SCC mixture design guidelines [14]. The sand /total aggregate mass ratio (S/A) was kept constant at 61% for all mixtures. The mixing procedure for all SCC mixtures was different than for the SCC containing AEA (S-6). The coarse and fine aggregates were first mixed with the one-third of the water in the mixer and then the cementitious and powdered materials were added to the main mixer. In the final stage, the HRWRA is mixed with the remaining water in a separate container and added to the main mixer and mixed for 3 min. The mixing procedure for the SCC containing AEA admixture was:

- Mix the dry coarse and fine gravel in the main mixer and then add one-third of the water.
- Mix1 liter of the water with the AEA admixture in a separate container and add it to the main mixer.
- Mix the components in the main mixer for 3 min to entrain air bubbles.
- Add coarse and fine sand with the one-third of the water to the main mixer and mix for 2 min.
- Add the cementitious and powdered materials to the main mixer.
- Add the HRWRA to the remaining water in a separate container.
- Add the HRWRA-water liquid to the main mixer and mix for 3 min.

Table 1
Properties of cement and mineral admixtures.

Compound/Property	Cement	LF	FA	LAGGBFS	SF	MK
SiO_2 (%)	22.58	0.76	61.25	33.35	87.49	55
Al_2O_3 (%)	4.45	1.4	31.45	10.64	2.87	41
Fe_2O_3 (%)	4	–	0.95	0.47	1.27	0.6
MgO (%)	3.05	12	1.15	10.83	1.31	0.3
K_2O (%)	0.4	–	0.41	0.5	0.41	2.83
SO_3 (%)	1.71	2.27	0.4	1.29	0.17	0.46
CaO (%)	61.68	42	2.67	35.8	1.55	0.03
Na_2O (%)	0.48	–	0.17	0.5	0.38	0.8
TiO_2 (%)	–	–	–	–	–	–
$CaCO_3$ (%)	–	–	–	–	–	–
Cl^-	–	–	<0.01	–	0.03	–
C	–	–	–	–	1.02	–
Equivalent alkali (Na_2O + 0.658 K_2O)	0.74	–	–	–	–	–
LOI (%)	1.07	40.94	0.84	0.63	1.92	2.56
Specific surface area (m^2/g)	2805	–	–	–	206,500	–
Specific gravity (g/cm^3)	3.15	2.6	2.3	2.75	2.25	2.8
Accelerated pozzolanic strength activity index; 7 days (%)	–	–	83	66	118	79
Accelerated pozzolanic strength activity index; 28 days (%)	–	–	110	106	163	117
TG pozzolanic activity (%)	–	–	60.69	35.87	85.76	48.56
Percent retained on 45-μm (No. 325) (%)	–	–	0.5	2.40	4.27	5.24
3 day compressive strength, MPa	17.8	–	–	–	–	–
7 day compressive strength, MPa	26.2	–	–	–	–	–
28 day compressive strength, MPa	38.4	–	–	–	–	–
Initial setting time, min	164	–	–	–	–	–
Final setting time, min	245	–	–	–	–	–

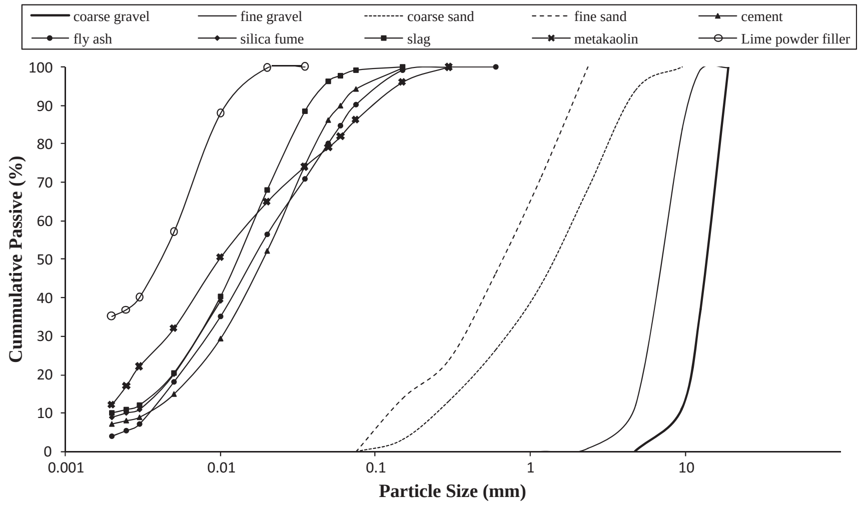

Fig. 1. Particle size distribution of solid materials.

Table 2
Mixture proportions of SCC mixtures.

Mix	w/cm	Quantities (Kg/m^3)									HRWR	AEA
		Cement	LF	Gravel	Coarse sand	Fine sand	SF	FA	MK	LAGGBFS	Percent weight of cementitious materials	
S-1	0.40	400	180	629	602	368	–	–	–	–	0.19	–
S-2	0.40	200	165	629	602	368	–	–	–	200	0.25	–
S-3	0.40	368	179	629	602	368	32	–	–	–	0.32	–
S-4	0.40	320	165	629	602	368	–	80	–	–	0.20	–
S-5	0.40	320	182	629	602	368	–	–	80	–	0.24	–
S-6	0.40	400	86	588	563	345	–	–	–	–	0.17	0.06

2.3. Test procedures

2.3.1. Workability of SCC mixtures

Workability testing of the fresh SCC mixtures for slump flow, T_{500} mm flow time, V-funnel, passing L-box ratio, L-box flow time, were conducted according to PCI instructions [15]. The density and air content of the freshly mixed concrete mixtures were measured via according to ASTM standards [16,17].

2.3.2. Hardened properties of SCC mixtures

2.3.2.1. Mechanical properties. Compressive strength was tested according to BS1881-116 [18], flexural strength according to ASTM C78-02 [19], impact strength according to ACI 544 [20] and abrasion resistance according to BS EN 1338 [21]. All analyses were done at 28 and 90 d. Compressive strength was measured at 7, 28 and 90 don cubic specimens of 100 mm.

2.3.2.2. Durability/transport properties tests. Volume absorption of concrete mixtures was determined according to ASTM C1585-04 [22] and permeability of the concrete was measured at 28 and 90 d according to BS EN 12390-8 [23]. Rapid freeze/thaw was tested according to ASTM C-666 [24]. This process was continued for 300 cycles or until the relative dynamic modulus of elasticity (RE_d) decreased 60%, whichever occurs first. Note that ASTM C 215 [25] was adapted to measure the RE_d of concrete specimens. The results of changes in relative dynamic modulus were collected; the length and mass changes of all species we rerecorded and evaluated. The changes in width were measured at a fixed location during the cycles.

3. Results and discussions

3.1. Workability of fresh SCC mixtures

Table 3 summarizes the workability results of the SCC mixtures. As seen, the slump flow of mixtures was in the range of the target value of 700 ± 20 mm. As indicated in Table 2, all mineral admixtures for SF, MK, LAGGBFS, and FA (S-2, S-3, S-4 and S-5, respectively) required higher HRWRA to reach the target slump flow.

Moreover, as seen in Table 4, the slump flow time (T_{500}) was generally less than 5 s. By application of mineral admixtures this time reduced indicating that these materials remarkably reduced the slump flow time of the SCC mixture. The use of FA and MK appeared to be the most effective in the reduction of the slump flow time.

As clearly seen in Table 3 that the contribution of FA and MK in the variation of the slump flow time were almost 40% and 50% while the effects of SF and LAGGBS were found to be about 10% and 18% respectively.

In a similar way to the slump flow, all mixtures but the SF or MK-contained mixture satisfied the EFNARC limitation [26] given

Table 3
Workability of SCC mixtures.

Mix	Slump flow (mm)	J-ring (mm)	V-funnel (s)	T_{500} (S)	L-box (H_2/H_1)	U-box (mm)	Air content (%)	Density	VSI
S-1	720	5.0	8.75	3.19	0.80	20	2.7	2.323	0.5
S-2	700	7.5	8.28	2.87	0.86	20	1.1	2.360	0
S-3	680	5.0	5.97	2.62	0.72	20	1.9	2.350	0
S-4	700	5.0	6.72	1.90	1.00	10	1.6	2.313	0
S-5	700	5.0	9.03	1.60	0.60	20	3.0	2.340	0.5
S-6	720	5.0	5.30	2.00	0.82	15	6.0	2.162	0.5

Table 4
Mechanical properties of SCC mixtures.

Mix	Compressive strength[a] (MPa)				Flexural strength (MPa)		Abrasion resistance (mm)		Impact strength (KN mm)	
	7-days	28-days		90-days	28-days	90-days	28-days	90-days	28-days	90-days
		a	b							
S-1	36	57.5	47.5	62.8	4.8	5.9	25.5	25.0	590	1142
S-2	26	38.3	30.8	46.7	4.9	5.8	28.2	24.7	285	742
S-3	42.5	57.5	47.5	58	5.5	6.3	26.5	26.0	476	857
S-4	34.7	52.8	42.5	58.8	5	6.7	26.8	25.5	400	800
S-5	34.7	44.3	34.5	53.7	4.6	5.6	25.2	24.7	400	819
S-6	26	34.8	28.4	41.83	4.3	4.5	27.0	26.8	457	971

[a] Cube specimen of size 100 mm.
[b] Cylindrical specimen of size 150 × 300 mm.

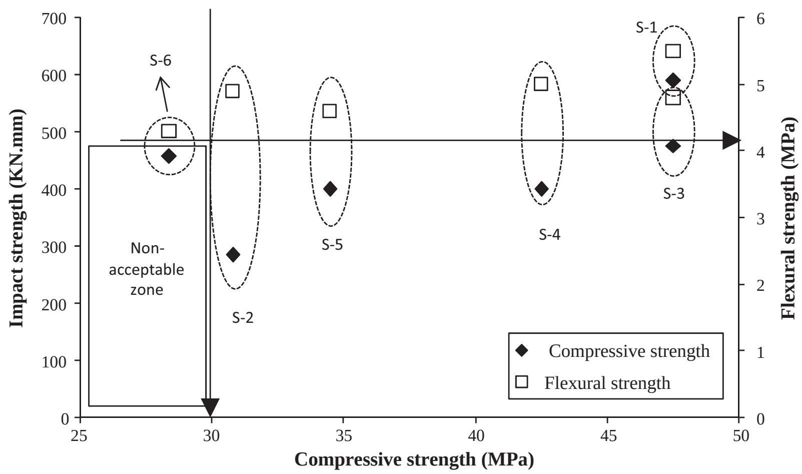

Fig. 2. Relationship of flexural/compressive strength with impact strength at 28 days.

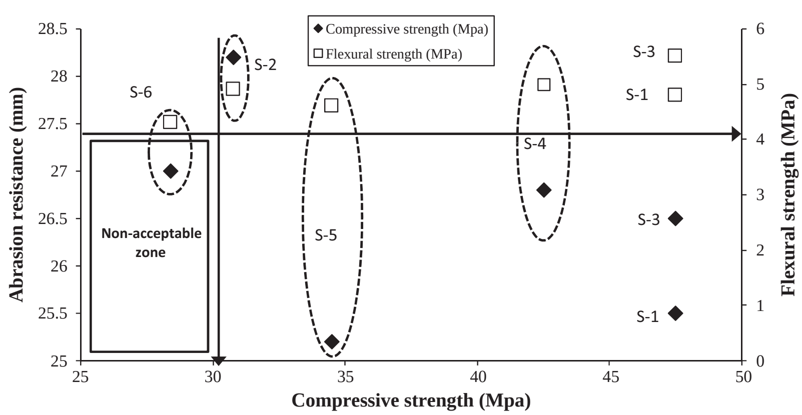

Fig. 3. Relationship of flexural/compressive strength with abrasion resistance value at 28 days.

Table 5
Transport properties of SCC mixtures.

Mix	Water absorption (%)			
	28 days		90 days	
	30′	24 h	30′	24 h
S-1	2.31	6.74	1.69	5.98
S-2	2.02	4.89	1.99	5.03
S-3	1.42	3.72	2.28	3.68
S-4	2.27	5.27	2.80	4.86
S-5	2.72	5.02	1.93	4.79
S-6	2.67	7.7	2.57	7.17

for the L-box height ratio. The ratio of H2/H1 was in the range of 0.8–1 for all concrete mixtures containing mineral admixtures. Especially, the concretes with FA provided better performance in terms of L-box test.

The time measured via the V-funnel flow was in the range of 5.97–9.03 s for mixtures containing mineral admixtures which fulfill the EFNARC recommendation.

Generally, mineral admixtures decrease the risk of particle segregation and increase paste viscosity of the SCC mixtures. Moreover, these results verify the findings by Ghoddousi et al. [27] and show that adding a chemical AEA (S-6) increases performance

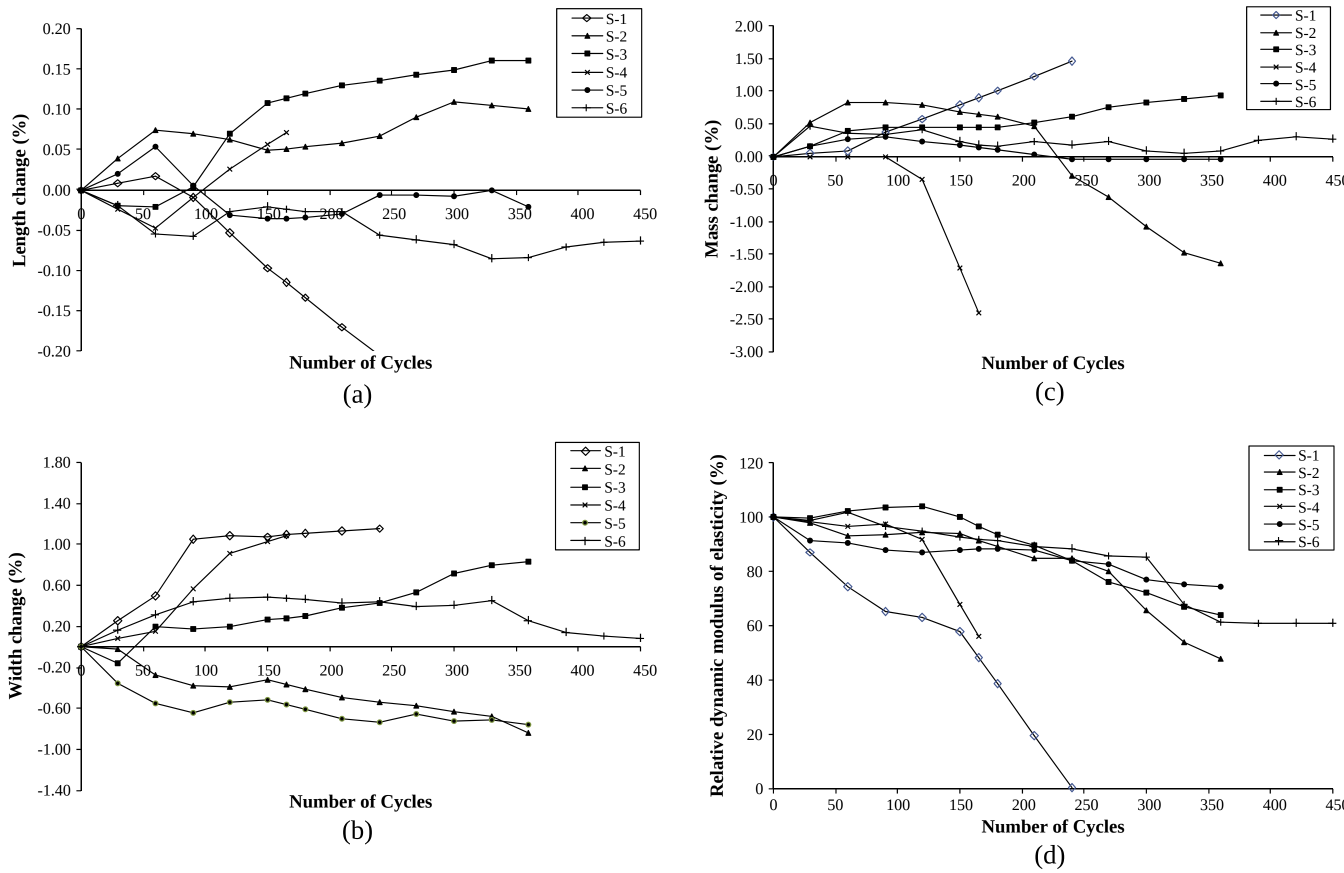

Fig. 4. (a) Length change, (b) width change, (c) mass change and (d) relative dynamic modulus of elasticity vs. the number of cycles for mixtures.

Table 6
DF and visual inspection results for SCC mixtures.[a]

Mix	DF	Visual inspection							
		Dimension constancy		Scaling/Map crack/Raveling		Long/Transverse cracking		Pop-outs	
		Inconstancy	Severity	Distress	Severity	Distress	Severity	Distress	Severity
S-1	29	√	H	√	H	√	H	√	L
S-2	65	×	–	√	H	×	–	√	H
S-3	72	×	–	√	M	√	M	√	L
S-4	31	√	H	√	H	×	–	√	H
S-5	77	×	–	√	M	×	–	×	–
S-6	85	×	–	√	M	×	–	×	–

[a] H: High, M: Moderate, L: Low.

(such as decreased need for HRWR in constant slump flows, decreased time for V-funnel testing).

In general, the mixture containing the FA (S-4) significantly increased workability of SCC. Due to its spherical shape, FA can disperse agglomeration of cement particles. When cement is replaced by FA, a lower dosage of HRWR is required to maintain the same filling ability [28].

3.2. Hardened concrete properties

3.2.1. Mechanical properties

3.2.1.1. Compressive strength. The compressive strength of SCC mixtures is presented in Table 4. As shown, adding LAGGBS (S-2) and chemical AEA (S-6) significantly decreased the compressive strength at7 day and 28 day compressive strength.

As it can be seen, compressive strength of SCC mixtures made with LAGGBS, FA, and MK experienced a decreasing trend in comparison with the reference mixture. After 28 days of curing, the amount of this decrease was about 50%, 9% and 30%, for LAGGBS, FA, and MK contained mixtures respectively, whereas after 90 days, these values reached to 34%, 7% and 17%. The overall improvements could be related to the pozzolanic activities and filling effects of these mineral admixtures.

The FAA [9,10] recommends that the minimum 28 day compressive strength for airfield pavement to be 30.3 MPa (150 × 300 mm cylindrical specimens). Table 4 indicates that mixtures S-6 and S-2 did not meet the recommended FAA criteria. The maximum early age strength was recorded for the mixture containing SF (S-3).

3.2.1.2. Flexural strength. Flexural strength at 28 d is the main parameter for the design of concrete pavement. Concrete must be designed so that the minimum 28 day flexural strength is greater than accepted criteria of 4.1 MPa for airport pavement.

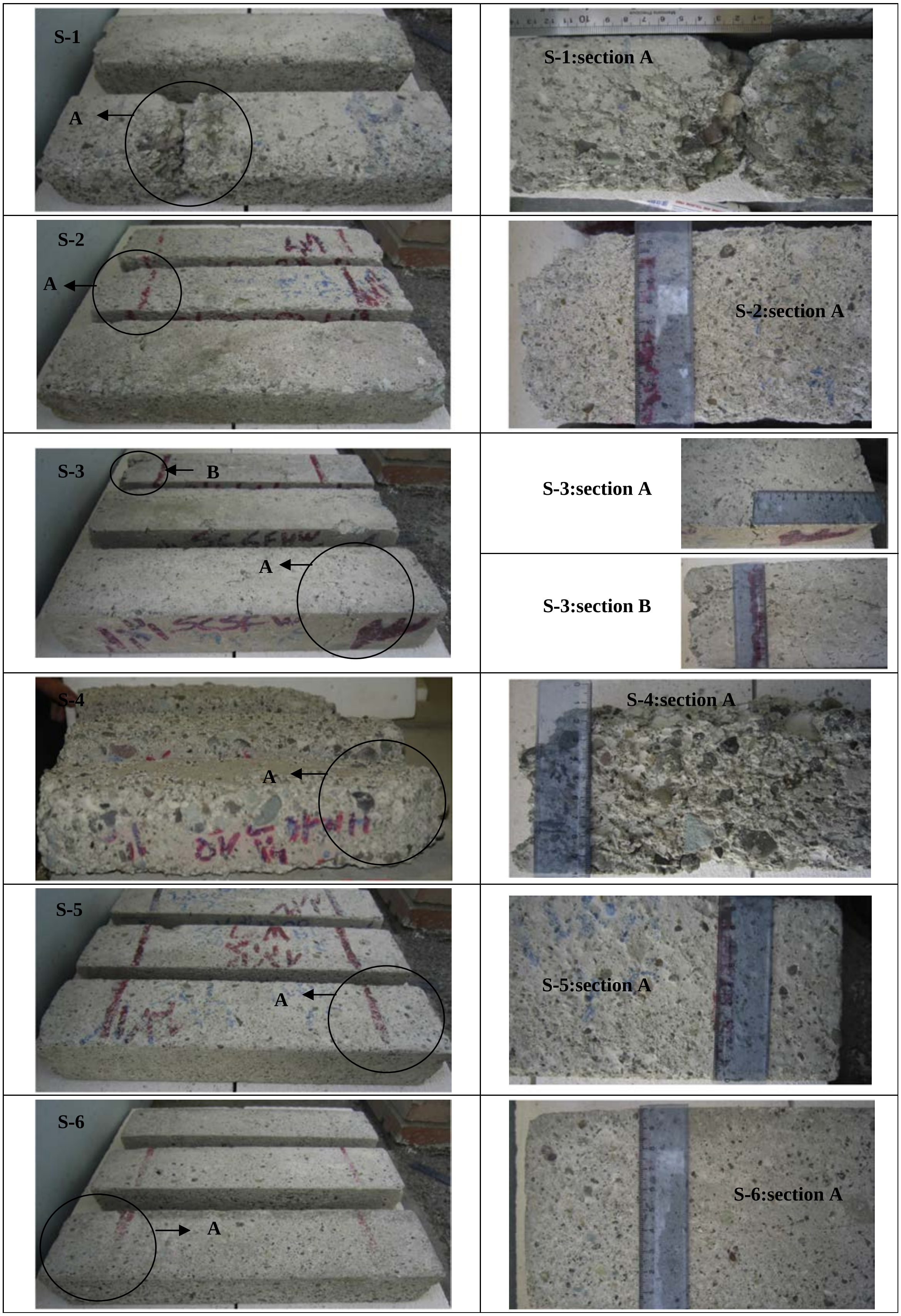

Fig. 5. Visual inspection for SCC mixtures.

The 90 day flexural strength is the basis for DMR. The results in Table 4 show that the 28 day flexural strength of all mixtures was greater than 4.1 MPa. The highest value was recorded for the mixture containing SF (S-2) and the lowest for the mixture containing AEA (S-6) with values of 5.5 MPa and 4.3 MPa respectively.

3.2.1.3. Impact strength. Because of the dynamic design loads experienced by airfield concrete pavement, the evaluation of concrete under impact conditions, specifically in the landing areas of the runway and the apron, is necessary. Table 4 reported the impact strength of understudy mixtures. It can be seen that application of mineral admixtures as SCMs led to decrease of impact strength.

As can be seen the impact strength improved from 28 days to 90 days attributed to the pozzolanic activities of the utilized admixtures. As can be seen, the highest and the lowest impact strength values at both 28 and 90 days were related to the reference and LGGBS contained mixture with values of 590 and 1142 kN-mm and 285 and 742 kN-mm respectively.

Fig. 2 represents the relationship between the mechanical properties of different mixtures at 28 d. The acceptable limit for impact strength is 480 kN/mm for compressive and flexural strengths of 30.3 MPa and 4.1 MPa. It can be seen that application of SCMs decreased impact strength.

3.2.1.4. Abrasion resistance value. Table 4 shows that, at 28 and 90 day, the highest and the lowest abrasion resistance was recorded for the mixture containing MK (S-5) and LGGBS with values of 25.2 mm and 28.2 mm respectively. Fig. 3 illustrates the relationship between 28 day compressive and flexural strength and abrasion resistance. Since the acceptance criteria for compressive and flexural strength are 30.3 MPa and 4.1 MPa, an acceptable limit of 27 mm for abrasion resistance is proposed.

3.2.2. Transport properties

3.2.2.1. Water absorption in 30 min and 24 h. Table 5 shows the results of volumetric water absorption of mixtures. The lowest value occurred in the mixture containing SF (S-3) and the highest occurred in the mixture containing AEA (S-6) and the reference mixture (S-1). These results are a response to the excessive porosity in the mixtures. The mineral admixtures, particularly S-3, filled out the capillary pores and decreased concrete porosity. Water penetration for the mixtures was acceptable at 10–20 mm.

3.2.2.2. Freeze and thaw. Fig. 4(a) to (d) shows the changes in length (LC), width (WC), mass (MC) and RE_d, respectively, versus the number of cycles for the different mixtures. Table 6 documents the results for freeze/thaw DF of SCC mixtures based on ASTM C666. DF was calculated as follows and the results summarized in Table 6:

$$DF = RE_d \times N/M \tag{1}$$

where RE_d is the relative dynamic modulus of elasticity at N cycles (%), N is the number of cycles for which P is the minimum value for discontinuing the test or the number of cycles at which exposure is terminated, whichever is less. M is the number of cycles for which exposure is to be terminated at 300 cycles.

DF results of <40% indicate concrete of unsatisfactory quality, DF of 40–60% indicates concrete of doubtful quality and DF of >60% indicates concrete of satisfactory quality [28].The table shows that the DF for the reference mixture and the mixture containing FA exhibited unsatisfactory performance for freeze/thaw resistance. The DF of S-2 containing LAGGBS was 65%, the lower level of satisfactory performance for freeze/thaw resistance. Mixtures S-3 containing SF and S-5 containing MK exhibited DF values of 72% and 77%, respectively, which indicate a satisfactory performance. Mixture S-6 containing AEA showed the best DF at 85%, suggesting it is the most appropriate mixture for freeze/thaw.

Fig. 5 shows the visual inspection of the samples after exposures and then recorded in Table 6. Based on ASTM C666, for non-AEA mixture, this parameter was inspected after termination of test. However, AEA mixture inspected after 450 cycles to identify the effects of air entrainment agent on freeze/thaw action. The types of distress (dimension constancy, scaling/raveling, cracking, pop-outs) are defined in Table 7.The following are brief descriptions of different mixtures:

- Freeze/thaw resistance for the reference mixture was about half of the maximum number of cycles (300). At cycle 150, RE_d was 60%. RE_d of the reference mixture reached zero after 240 cycles. This result can be attributed to macro-transverse cracking at 7 cm from the center of the sample. The propagation of internal cracks during freeze/thaw caused disintegration of the concrete and an MC of about 1.44% [15].
- The application of 50% LAGGBS in S-2 increased DF to about 124% over that of the reference mixture, extending the number of freeze/thaw cycles to more than 165. A decreasing trend for RE_d began after cycle 270; at cycle 315, RE_d was 60%. MC was calculated to be 1.64% at the termination of freeze/thaw testing; damage included partial pop-out of materials at the edges of the samples that led to partial dimensional instability. No cracks were observed in this mixture.
- Application of 8% SF in mixture S-3 increased DF to about 148% over that for the reference mixture and produced good performance of concrete subject to freeze/thaw testing for the maximum number of cycles. An MC of about 0.93% was the result of caused by small internal/surface cracks that developed toward the edge of the sample and during the freeze/thaw cycles. These cracks resulted in pop-out of materials and paste from the edges of the concrete. Moderate scaling was also observed.
- Mixture S-4 with 20% FA had a MC of about 2.4%, the highest mass loss of all mixtures. The LC was higher than the permissible limit of 0.1% [29]. The decreasing trend for RE_d began at cycle 100 and terminated at cycle 165 when significant scaling occurred. Considerable dimensional instability was observed, but there was no cracking evident.
- The SSC mixture with 20% MK showed the best performance for FTR, with dimensional stability and no cracking. Moderate scaling was observed at the termination of the test.

Table 7
Definition of the modes of distress.

Mode of distress		Definition
Dimension constancy		Variation in dimension of specimens
Scaling/Map crack/ Raveling	Scaling	A general loss of surface mortar or mortar surrounding the coarse aggregate particles on a concrete surface.
	Map crack	A network or shallow, fine, or hairline cracks that extend only through the upper surface of the concrete.
	Raveling	Wearing away of the pavement surface caused by the dislodging of aggregate particles and loss of cement paste.
Long/Transverse cracking		These cracks, usually divides the pavements into two or three pieces.
Pop-outs		Small piece of concrete that freeze thaw action, combined with aggregate expansion, causes to break loose from the surface.

- The highest DF was for mixture S-6 containing AEA, which was the apparent cause of the value. The addition of AEA increased the number of cycles needed to reach a dynamic modulus of 60% to 470 cycles. This was an increase of 320 cycles over the 150 cycles for S-1.

Internal cracking and damage caused by cyclic freeze/thaw action were evaluated using the parameters of change in length and modulus of elasticity. There is typically a close relationship between change in mass and damage caused by scaling.

4. Conclusions

The following conclusions can be drawn from the results of this research:

- MK, LAGGBFS and SF increased the viscosity of mixtures over that of the reference mixture. Fly ash visibly increased the workability of the concrete.
- All mixtures having mineral and chemical admixtures met acceptable levels of compressive and flexural strength for the design of airfield concrete pavement based on FAA regulations.
- The application of all mineral and chemical admixtures except fly ash increased the durability and all visual inspection parameters.
- Abrasion resistance and impact strength limits were proposed for this study. Established correlation diagrams propose values for abrasion resistance of 480 kN-mm and impact strength of 27 mm.
- AEA with the lowest amount of HRWRA had highest DF for freeze-thaw durability and visual inspection parameters.
- The results indicate that MK is the most effective of the mineral admixtures tested for increasing freeze/thaw durability and visual inspection parameters.

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