Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2015/04/jls.htm
2015 Vol. 5 (S4), pp. 147-153/Hashemi et al.

Research Article

THE EFFECT OF POZZOLANS ON COMPRESSIVE STRENGTH AND ABRASION RESISTANCE OF SELF-COMPACTING CONCRETE IN PAVEMENT

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ABSTRACT
Self-compacting concrete (SCC) was first developed in Japan. Due to its various advantages, SCC application in different parts of civil engineering such as pavement of routes, runways and parking lots gained attentions. A favorable concrete overlay should have high strength and an appropriate strength against friction of tires of cars (abrasion resistance). One method that may improve abrasion resistance of concrete overlay is improvement of microstructures and compressive strength of concrete. To do so, two types of pozzolans including metakaolin and silica fume with different percentages were replaced with different percentages by cement and exposed to compressive and bending strength experiments. The results show that strength is improved considerably in an optimal amount of pozzolan. Abrasion resistance experiment was also conducted according to ASTM C 779; the results show that the pozzolans improve admixture strength and improve abrasion resistance of concrete in an optimal amount of pozzolan.

Keywords: *SCC, Metakaolin, Silica Fume, Compressive Strength, Abrasion Resistance*

INTRODUCTION
Self-Compacting Concrete (SCC) or the new generation concrete is a modem technology in the field of construction in the world. As per ACI237R-07 (ASTM, 2003) SCC is a concrete with high efficiency and no segregation that may be poured in a relevant place, may fill mold space, and cover round rebar's without any need for mechanical compression. It is reasonable to apply SCC in concrete pavement of routes and runways due to compression of rebar and need for strength. Therefore, while observing the above parameters in designing concrete pavement, the cement concrete overlay should have high abrasion resistance to prevent early failure in pavement. Literature results show that concrete abrasion resistance is influenced by different parameters such as compressive strength of a concrete admixture. Pozzolans are the materials that improve SCC’s strength. Today, most concrete manufacturers in the world realized value of pozzolans efficiency for their products and they use them as an essential part and/or even a usual component of concrete where they are available. Pozzolans react with the calcium hydroxide generated due to cement hydration and produce calcium silicate hydrate (C-S-H) that may improve concrete microstructures and improve concrete’s cohesion and strength. Silica fume and metakaolin are among these pozzolans. Metakaolin is a white amorphous aluminum silicate with pozzolanic properties and it is categorized into Class N pozzolans according to ASTM C 618 (ASTM, 2012). Containing more than 90 percent of silica in a non-crystalline state and tiny particles with average diameter of 0.1 micron, silica fume is severely pozzolanic and it is suitable as a cementitious material. To do so, this research evaluates replacement of pozzolans by a percentage of cement by creating 7 mix plans. It also compares it with the proposed minimum requirements stated in the FAA’s (Federal Aviation Administration) regulation.

Literature Review
There has been a considerable growth of using concrete as the final pavement; however, low stability and strength against friction of vehicles especially when they brake or the time airplanes land on runways is among its problems. SCC is a modem type of concrete that combines high consistency and high segregation strength by using a large amount of fine aggregate and superplasticizer. This type of concrete

is poured without compression and there is no environmental problem caused by vibration noise. In addition, the strength and stability problems (such as abrasion resistance) caused by insufficient compression are removed (Turk & Karatas, 2011). The research results on abrasion resistance showed that abrasion resistance of concrete is under the influence of compressive strength, concrete surface curing techniques, type of adhesion, aggregate specifications, and experiment conditions (i.e. wetness and dryness). Liu (2007) reported that abrasion resistance is increased by adding silica foam. For a concrete with surface crack size of 1 mm and water flow on the crack, abrasion resistance is respectively 13% and 25% higher than control admixture (Tsong & Liu, 2007). Siddique (2004) reported that abrasion resistance of concrete admixtures with FA was lower than the one of control admixtures and it reduced with the FA content increasing. Siddique (2003) studied the effect of replacing fine aggregate (10%, 20%, 30%, and 40%) by Class F fly ash on abrasion resistance and compressive strength of concrete within a 365-day period. The results show that compressive strength and abrasion resistance of concrete admixtures increased with the increasing of replacement percentage of fine aggregate by fly ash. By replacing 40 percent of fine aggregate by fly ash, abrasion resistance of the concrete was improved by almost 40 percent more than the reference concrete (Siddique, 2003). Yen *et al.*, (2007) examined abrasion-erosion resistance of high-resistance concrete mixes by replacing cement (15%, 20%, 25%, and 30%) by fly ash. They concluded that abrasion-erosion resistance of concrete-fly ash mixes increased by increasing compressive strength and reducing water-cement materials coefficient. They also found out that abrasion-erosion resistance of concrete was comparable with the concrete without fly ash by replacing maximum 15 percent. By replacing less than 15 percent of fly ash, abrasion-abrasion resistance of fly ash concrete was less than the one of the concrete without fly ash (Yen *et al.*, 2007). Rafat *et al.*, (2012) calculated abrasion resistance of HVFA (High volume fly-ash) concretes made by replacing 30%, 40%, and 50% of cement by fly ash. The results showed that abrasion resistance of the concrete containing 30 percent fly ash was comparable with the one without fly ash. The concretes containing more than 30 percent of fly ash showed a slightly lower abrasion resistance than the control concrete.

MATERIALS AND METHODS

Methodology

Consuming Materials

This study used Portland cement Type I (pc.42.5) made by Soufian Cement Factory in Tabriz, Iran and metakaolin and silica fume were added to the admixture as cement replacement pozzolan. Table (1) shows the chemical and physical composition of Portland cement, metakaolin, and silica fume. Natural sand with fineness modulus of 3.05 and gravel with nominal size of maximum 20 ml as aggregate was used in the admixture. In addition, sp-1 was used as a superplasticizer to control water-cement ratio and improve concrete efficiency.

Table 1: Chemical analysis and physical properties of pc, Mk and Sf (%)

Chemical composition of Portland Cement, MK and SF			
Component	PC (%)	MK (%)	SF (%)
SiO_2	21.3	52.1	91
Al_2O_3	52.4	42.6	0.58
Fe_2O_3	3.24	1.6	0.24
CaO	-	0.2	0.71
MgO	2.66	0.21	0.33
SO_3	1.75	0.00	-
K_2O	-	0.32	-
Na_2O	-	0.11	
Physical properties:			
Specific Surface(m^2/g)	0.33	2.54	
Specific Gravity	3.15	2.6	

Mixing Ratio

Assuming saturated surface dry (SSD) conditions of aggregates, Table (2) shows the mixing ratio of VTC sample and SCC samples. Only Portland cement was used for the VTC sample. For the SCC samples, metakaolin and silica flume with 5-15 weight percent of cement was replaced by cement with 5 percent sequence. Water-cement materials ratios of all the mixes were adjusted on 35 percent and superplasticizer content was considered as 1 percent of cement weight.

Table 2: Mix proportion

Mix ID	Cement (kg/m^3)	kg MK	SF	Water (kg/m^3)	w/c	Sand (kg/m^3)	Gravel (kg/m^3)	HRWR (kg/m^3)
VTC	390	-	-	137	0.35	967	817	-
SCC 5 MK	370.5	19.5	-	137	0.35	975	805	3.7
SCC 10 MK	351	39	-	137	0.35	975	805	3.50
SCC 15 MK	331.5	58.5	-	137	0.35	975	805	3.30
SCC 5 SF	370.5	-	19.5	137	0.35	975	805	3.7
SCC 10 SF	351	-	39	137	0.35	975	805	3.50
SCC 15 SF	331.5	-	58.5	137	0.35	975	805	3.30

Making Samples and Conducting Experiments

Two series of experiments are used in SCC for fresh and hardened concrete. The fresh concrete, which is made before making samples, is merely for diagnosing concrete status. Compatibility of the test results with the ones of the proposed values indicates self-compactness of the concrete. This project measured efficiency of Vibrated Traditional Concrete (VTC) as per ASTM C 143 (ASTM, 2002) standard using Slump test. In addition, Slump-Flow, T_{50s}, LBOX, V_{funeel} experiments were carried out as per EFNARC on SCC fresh concrete samples.

Following table shows physical specifications of all the fresh samples. The results show that all the SCC concrete samples are in good conditions as far as slump flow, filling, passing ability, and segregation resistance are concerned.

After obtaining of fresh concrete specifications for making samples, a process similar to the one used by Khayyat *et al.*, (2002) were applied. Based on this, aggregates, including gravel, sand were mixed in a concrete mixer for 30 seconds. Then, half of the consuming water was added to the mix while the concrete mixer was in operation. The concrete mixer was stopped for one minute after this stage and the filming agent materials including cement, metakaolin and silica fume were added and mixed in the concrete mixer for 1 minute.

While the concrete mixer was in operation for 3 minutes, the remaining water and superplasticizer additive were added to the admixture. After resting for 2 minutes, it was mixed for another 3 minutes. Finally, the fresh concrete was poured in the square lubricated 150 x 150 x 150 molds for compression strength test. Some 150 x 150 x 450 mm prisms and some 100 x 300 x 300 prisms were made for conducting bending tests and abrasion test, respectively. After 24 hours, the samples were removed from the mold and stored in a room with standard humidity at 25°C. Compression strength experiment, bending resistance test, and abrasion resistance test of the samples were conducted according to ASTM C 39 (2002), ASTM C 78 (2003) and ASTM C 779 (2002) standards, respectively.

Table 3: Properties of fresh concretes

MIXTURE	**VTC**	**SCC With SF**			**SCC With MK**		
		SF 5	**SF 10**	**SF 15**	**MK 5**	**MK10**	**MK 15**
Slump (mm)	68	707^b	701^b	703^b	660^b	700^b	690^b
$T_{50\ Cm\ (S)}$		2.30	2.9	3.8	2.7	2.6	3.4
L – Box H_2/H_1		0.865	0.876	0.856	0.806	0.817	0.834
V_{funnel}	-	15.3	17.9	18.7	14.5	19.6	18.8

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RESULTS AND DISCUSSION

Evaluation of Results

Compression Strength

Figure (1) shows compression strength of the traditional concrete and SCC containing metakaolin and silica flume for ages 3 and 28 days. The results show that compression strength of the SCC samples is higher than the one of VTC sample. SCC contains 5 percent silica flume (SFS) with 32.9 MPa has the highest compression strength for 3 days. This is due to the high natural activity of silica flume during early ages in the presence of cement that is able to provide a considerable amount of calcium silica hydrate (C-H-S) in an optimal amount. SF10 plan with 59.7 MPa had the most compressive resistance within 28 days. Silica fume is a more active pozzolan and its incremental effect on compressive strength of SCC is due to the ability of silica fume to maintain strength between aggregates and cement paste.
As Figure (2) shows, for the plans containing metakaolin, maximum strength belonged to mk10 plan within 28 days and the strength is reduced by decreasing or increasing its content. However, the 3-day concrete samples containing metakaolin show that strength is reduced by decreasing metakaolin consumption. Figure (2) shows that compressive strength in the plans containing microsilica is obtained in sf10 plan and the strength is reduced by decreasing and increasing its content, whereas the 28-day strength of sf5 exhibits the highest strength. Since silica flume is fully pozzolanic in the presence of cement and the complete mix with cement needs humidity, further use of silica fume makes us need more time for hydration. Therefore, the mix strength of sf5 in 3 days exceeds the one of sf10. According to the results, the optimal value of silica fume and metakaolin is 10 percent of the cement weight.
The compressive strength results were controlled by the minimum requirements for runway pavement proposed by FAA - that is 41.35 MPa. It is observed that the plans containing silica fume and metakaolin have acceptable values even for a runway pavement. However, the minimum value was not achieved in VTC admixture.

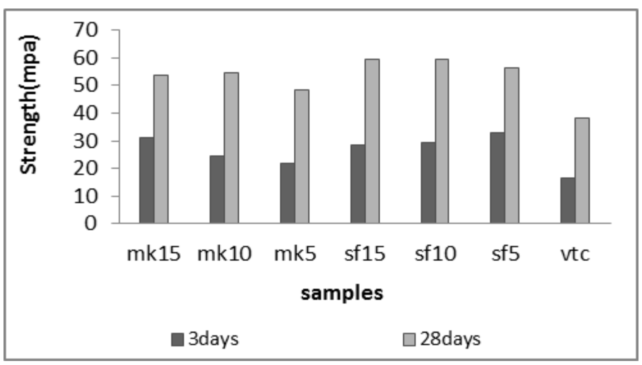

Figure 1: Compressive strength of concretes for 3 and 28 days

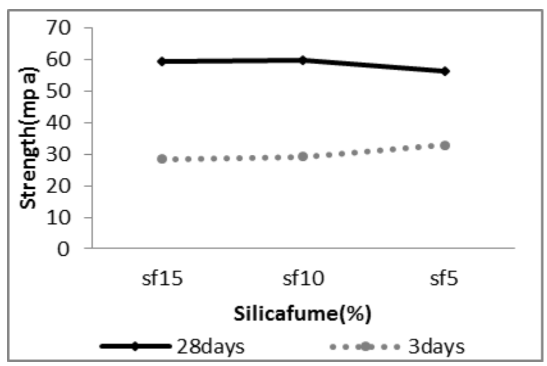

Figure2. Compressive strength of concretes for 3 and 28 days with sf

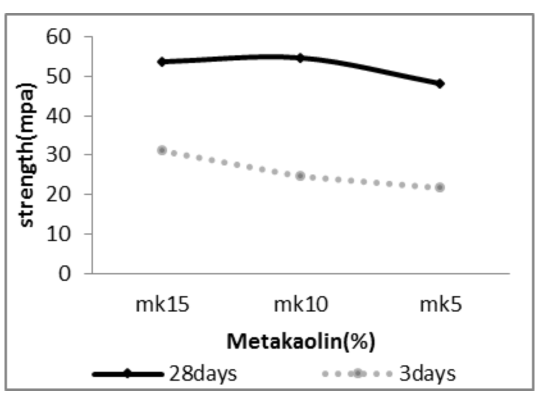

Figure 3: Compressive strength of concretes for 3 and 28 days with mk

Bending Strength

Figure (5) shows the bending strength of VTC and SCC concretes containing metakaolin and silica fume after curing in water for 28 days at 25°C. The MK- and SF-containing samples show the bending strengths, which exceed the one of VTC. SF10, SF15, mk10 plans show maximal bending strength. As expected, bending strength increased with the concrete compression increasing.

Figure (4) shows that bending strength has almost a linear relationship with compressive strength. That is, bending strength increases with the compressive strength increasing. Bending strength reduces with the compressive strength decreasing. Figure (1) shows that bending strengths of SSC admixtures under the best and worst conditions are respectively 60% and 25% more than the ones of the traditional concrete. As compared with the minimum requirements proposed by FAA (the minimum compressive strength for a runway pavement is 41.35 MPa), SCC plans are favorable for runway pavement. As shown by Figures 6 and 7, the optimal value of bending strength was achieved using 10 percent of silica fume and 10 percent Metakaolin.

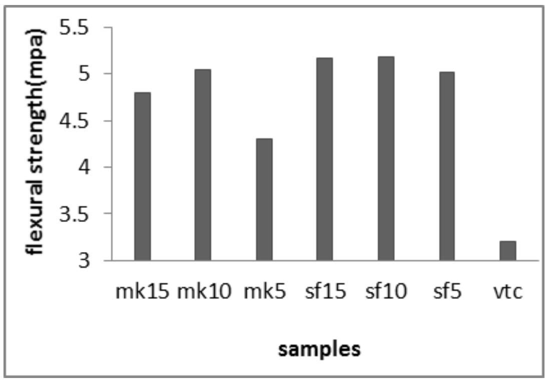

Figure 4: Flexural strength of concretes for 28 days

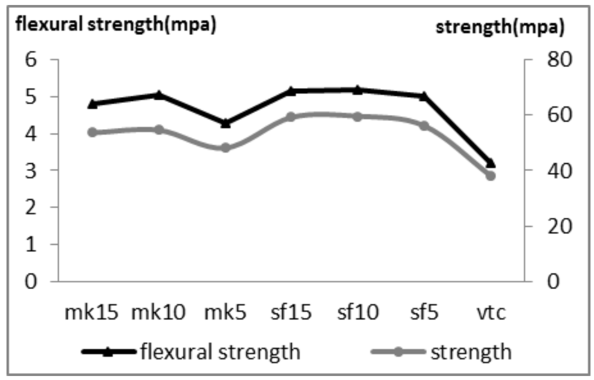

Figure 5: Comparison between flexural and compressive strength of concretes

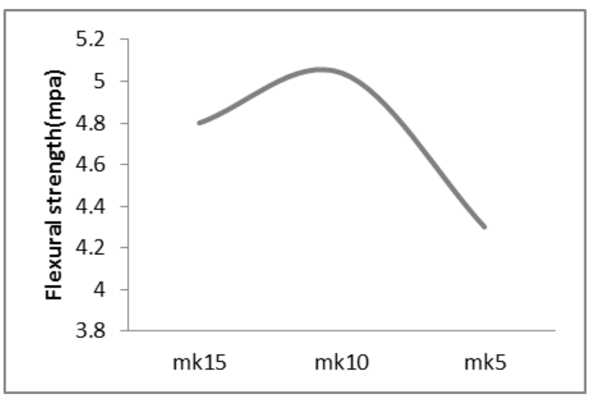

Figure6. Flexural strength of concretes for 28 days with mk

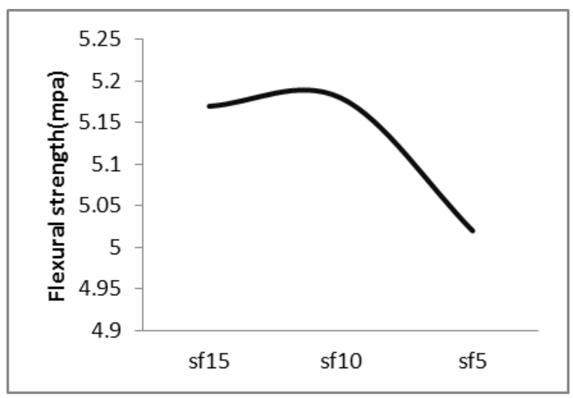

Figure 7: Flexural strength of concretes for 28 days with sf

Abrasion Resistance

Figure (4) shows abrasion depth of all the concrete samples under water curing for 28 days at 25°C. The results show that SCC samples containing metakaolin and silica fume have lower abrasion depth as compared with the VTC sample. Meanwhile, abrasion resistance of the SCC samples containing 10 and 15 percent of silica fume was more than the one of other samples. One of the major reasons to explain why the abrasion resistance of the SCC containing silica fume is higher than conventional concrete is that silica fume provides strengths among aggregate particles and cement paste through physical and chemical impacts on cement hydration process. This happens in the presence of more tangible silica fume. It also

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shows that by replacing 10 percent of metakaolin in the metakaolin-containing plans, the minimum rut depth was obtained.
Figures (5) and (6) shows that abrasion depth decreases with the increasing of compressive strength and abrasion depth increases with the reducing of compressive strength. As shown by Figure (5), the compressive resistance and abrasion resistance have not changed much with the increasing of consuming silica fume from 10 to 15 percent. It indicates that consumption of silica fume more than 10 percent does not have considerable impact on strength specifications of concrete. As the minimum abrasion depth was obtained in sfl0 and mk10 plans, it can be concluded that the optimal amount for reducing abrasion depth in the presence of 10 percent silica flume and 10 percent metakaolin.

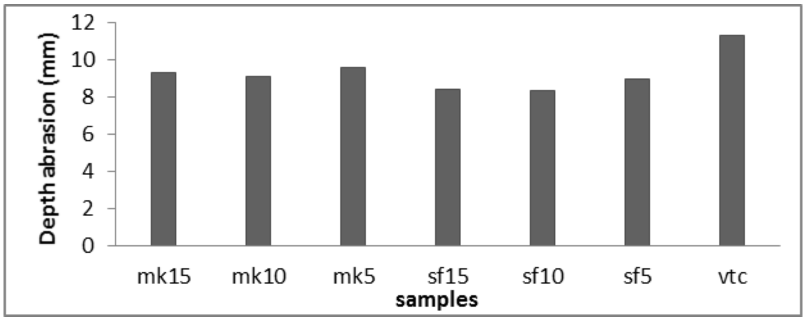

Figure 8: Abrasion resistance of concrete samples

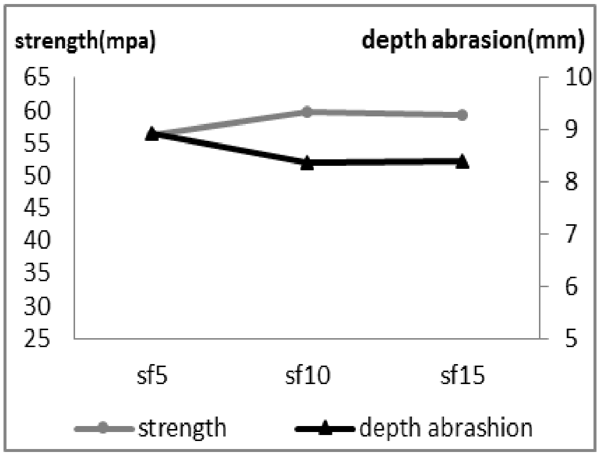

Figure 9: Relation between 28-day compressive strength and loss on wear of scc with sf

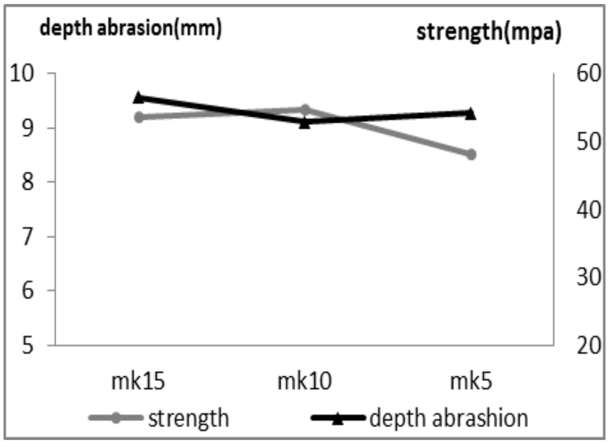

Figure 10: Relation between 28-day compressive strength and loss on wear of scc with mk

Conclusion and Recommendations

1-The results show that 10 percent silica flume and 10 percent metakaolin provide utmost compressive strength, as the resistance of silica fume - even in 5 percent silica fume - exceeds metakaolin with different percentages.
2- Bending strength is maximized by adding 10 percent silica fume and metakaolin. Meanwhile, the bending strength obtained from silica fume exceeds the one of metakaolin and increasing more than 10 percent of cement weight does not lead to a considerable change in resistance and the resistance is reduced by a mild slope.
3- It was also specified that adding an optimal amount of pozzolan to SCC admixture increases abrasion resistance considerably, which is 22% and 16% under the best and worst conditions, respectively. The increase of abrasion resistance in SCC was higher than the one of the conventional concrete. Moreover, SCC provides necessary conditions for being applied in runways. The diagram specified that compressive strength has an almost linear relationship with bending resistance and abrasion resistance.

ACKNOWLEDGEMENT
This study was sponsored by the Islamic Azad University, Germi Branch, iran. The opinions, findings and conclusions presented here are those of the authors and do not necessarily reflect those of the research sponsors.

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