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Effect of strength class of concrete and curing conditions on apparent volume of permeable voids of self-compacting and conventional concrete

[Emine Ebru Demirci, Remzi Şahin]

Abstract—The purpose of this study is to compare Self Compacting Concrete (SCC) and Conventional Concrete (CC) which are used in beams with dense reinforcement, in terms of their apparent volume of permeable voids (AVPV). During the comparison of SCC and CC, the effects of two different factors were also investigated: strength class of concrete and curing condition. In the study, both SCC and CC were produced in three different strength classes (C25, C50 and C70) and the other parameter (i.e. curing condition) was determined as two levels: moisture and air curing.

Beam dimensions were determined to be 200x250x3000 mm. The AVPV measurements were performed on core samples taken from the beams. Core samples of ø8x5 cm were taken from the beginning (0-100 cm), middle (100-200 cm) and end (200-300 cm) region of the beams according to the casting direction of SCC. In the study, AVPV experiments were performed according to Turkish Standard 3624.

It was observed that, for both SCC and CC, AVPV values of samples kept in moisture curing are significantly lower than that of samples stored in air curing. For CC's; C25, C50 and C70 class moisture-cured samples were found to have 6%, 6% and 10% lower AVPV values, respectively, when compared to the air-cured ones. For SCC's; these values were 4%, 8% and 13%, respectively. It was also found that, for both curing environments and all strength classes of concrete, SCC's had lower AVPV values than that of CC's. The AVPV values of C25 class of SCC are 7% and 5% lower than that of C25 class of CC for air and moisture conditions, respectively. For C50 class, these decreases were 7% and 9%, while for C70 class, they were 10% and 13%, respectively. Apart from that, it was determined that AVPV values for both SCC and CC decrease with increasing strength class of concrete for both curing environments. It was found that, for air cured CC, C50 and C70 class of concretes had 16 % and 35 % lower AVPV values compared to the C25 class of concrete. For the same type of concrete samples cured in the moisture environment, these values were found to be 16% and 38%. It was found that for SCC samples, AVPV value of C50 and C70 concretes, which were kept in air curing, were 16% and 37% lower than that of C25, while for moisture-cured samples these values were 19% and 43%, respectively.

When standard deviations of the AVPV values are compared for core samples obtained from the beginning, middle and end of the CC and SCC beams, it was found that, in all three strength classes of concrete, the variation is much smaller for SCC than CC. This demonstrated that SCC's had more uniform character than CC's.

Keywords: Self compacting concrete, reinforced concrete beam, apparent volume of permeable voids (AVPV), strength class, curing condition

I. *Introduction*

Self-compacting concrete is described as a special, high-performance concrete type which can fill narrow and deep sections with dense reinforcement with its own weight, can be squeezed itself without requiring any internal and external vibration, can keep cohesion without causing segregation and bleeding while providing these features, and has properties of high fluidity and passing [1].

Along with the exploration of SCC (self-compacting concrete), it has been initially thought that SCC can be used in the production of elements where reinforcement is too dense and vibrators are not able to reach [2, 3, 4]. But, usage of SCC started afterwards in production of high curtain walls and in maintenance and reinforcement works of reinforced concrete structures [3, 4]. However, SCC has been

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TABLE 1. SCC usage by countries as of 2011 and 2012 [8]

<table>
<tr><th>Country</th><th>2011</th><th>2012</th><th>Country</th><th>2011</th><th>2012</th></tr>
<tr><td>Austria</td><td>1</td><td>1</td><td>Slovakia</td><td>1</td><td>0</td></tr>
<tr><td>Belgium</td><td>0.5</td><td>0.5</td><td>Spain</td><td>1</td><td>1</td></tr>
<tr><td>Czech Republic</td><td>1</td><td>1</td><td>Sweden</td><td>7</td><td>7</td></tr>
<tr><td>Denmark</td><td>35</td><td>35</td><td>England</td><td>2</td><td>2</td></tr>
<tr><td>Finland</td><td>1</td><td>1</td><td>Europe Avg.</td><td>2</td><td>2.2</td></tr>
<tr><td>France</td><td>5</td><td>6</td><td>Israel</td><td>1</td><td>1</td></tr>
<tr><td rowspan="2">Germany</td><td rowspan="2">1</td><td rowspan="2">1</td><td>Norway</td><td>4</td><td>4</td></tr>
<tr><td>Switzerland</td><td>-</td><td>-</td></tr>
<tr><td>Ireland</td><td>1</td><td>1</td><td>Turkey</td><td>0.8</td><td>1</td></tr>
<tr><td>Italy</td><td>1</td><td>1</td><td>ERMCO Avg.</td><td>1.8</td><td>1.9</td></tr>
<tr><td>Netherland</td><td>2</td><td>2</td><td>Russia</td><td>1</td><td>1</td></tr>
<tr><td>Poland</td><td>1</td><td>1</td><td>USA</td><td>1</td><td>1</td></tr>
<tr><td>Portugal</td><td>2</td><td>0</td><td>Japan</td><td>1</td><td>1</td></tr>
</table>

using with increasing rates in ready-mixed and prefabricated concrete industry [5]. Nevertheless, some researchers (for instance [6] and [7]) had the prediction that SCC now has a transition period and this period is easy and fast in developed countries, whereas slow and problematic in developing countries. During the period up to now, despite this prediction was partially verified, it cannot be said that it was occurred at all. As a matter of fact, based on the data (Table 1) obtained by European Ready Mixed Concrete Organization (ERMCO), as of 2012; despite 35 % of concretes produced in Denmark is SCC, it is still 1% in Japan which is a developed and mother country of SCC. From this point of view, it is concluded that theoretical and practical studies on this type of concrete will result in widening usage areas of SCC all around the world.

On the other hand, there are voids formed by different reasons in hardened concrete [9, 10, 11]. Whole factors affecting the volume of voids in concrete are also the factors which have influence on permeability [9]. Permeability is a significant property for durability of concrete [12, 13, 14, 11, 15, and 16]. Because of the fact that transfer of water and detrimental materials into concrete would be easy in concretes with high permeability, this causes damage on both concrete and the steel embedded in concrete or causes more than one damage at the same time [17, 18, 14, 19]. Therefore; permeability is usually an indicator of damage rate [20, 9].

Furthermore; in literature, some results that are contradictory to each other were introduced in the studies which have been conducted on small cylindrical samples produced in laboratory for comparison of SCC and CC (conventional concrete) porosities. As many researchers (for instance ref. [21], [22], [23] and [24]) have stated that SCC has lower porosity than CC, some researchers (for instance; ref. [5]) have stated that porosity of SCC mixtures is slightly higher than CC independent from the strength class they have. Thus; within this study, CC and SCC samples of same concrete class were produced and comparison between these two concrete types was done considering volume rates of permeable voids in these concretes. Experiments were carried out on core samples obtained from reinforced concrete elements to be able to reflect real service conditions. Core samples were obtained from beginning, middle and end section of the beam according to the casting direction, and therefore comparison between SCC and CC was done with regard to uniformity.

II. *Materials and Methods*

A. *Materials*

In the experiments, one type of cement (CEM I 42,5R) and F-type fly ash according to (ASTM C 618 [25]) were used, see Table 2 for properties. Crushed stone (white limestone) with a maximum particle size of 16 mm and river sand were used as coarse and fine aggregates, respectively, while white limestone with a particle size lower than 125 µm was employed as filler. While specific gravity of filler was 2.74, that of aggregates was 2.51 for 0-2 mm, 2.59 for 2-4 mm, 2.77 for 4-8 mm and 2.61 for 8-16 mm. Water suction values of aggregates were 2.10 % for 0-2 mm, 2.35 % for 2-4 mm, 1.12 % for 4-8 mm and 0.61 % for 8-16 mm. New generation super plasticizer, i.e., polycarboxylic ether with a density of 1.04 kg/dm^3 and chloride ion content of less than 0.1 %, and an ordinary plasticizer, i.e., naphthalene sulfonate with a

TABLE 2. The chemical composition and physical characteristics of the cement and fly ash

	Cement (CEM I 42,5R)				Fly ash			
Chemical composition (%)	SiO_2	19.66	SO_3	2.95	SiO_2	57.34	SO_3	0.51
	Al_2O_3	5.55	Na_2O	0.13	Al_2O_3	26.90	Na_2O	0.12
	Fe_2O_3	3.03	K_2O	0.78	Fe_2O_3	6.23	K_2O	0.66
	CaO	62.61	Cl	0.0095	CaO	2.21	Cl	0.025
	MgO	2.27	Insol. residue	0.35	MgO	2.36	Loss of ign	2.58
Physical characteristics	Blaine (cm^2/gr)		3459		3550			
	Specific Gravity		3.10		2.19			
	Compr. Strenth (28 day.,MPa)		52.7		-			

density of 1.16 kg/ dm^3 and chloride ion content of less than 0.1 % were used as additives for SCC and CC, respectively. S420 type (with rib) stirrup ø8 and plain rebar ø12 were used at the beams.

B. *Parameters, Curing Methods and Designation of the Mixtures*

During the comparison of SCC and CC, the effects of two different factors were also investigated. These are concrete strength class and curing conditions, which constitute the most frequently encountered variables in the application. In the application different concrete types are used due to various structural reasons. On the other hand, curing conditions are one of the most important factors specifying concrete properties particularly concrete cover [11,26].

Both SCC and CC were produced in three different concrete classes. These are;

i- C25/30, since it is the mostly consumed concrete type in Turkey (39 %) [27],

ii- C50/60, since it is the lower boundary of the high strength concrete class according to Turkish standards (TS 500 [28]) and (TS EN 206-1 [29]), and

iii- C70/85, since it is the lower boundary of the high strength concrete class determined by Strategic Highway Research Program in USA [30].

In the study, the parameter of curing conditions was determined as two levels. These are moisture cure, which slightly represents the curing method in the application, and air cure, which represents the simple curing conditions. However, Bordeleau *et al.* [31] and Kukko [32] proposed that curing in air represents cure of concrete in-situ conditions.

Curing regime was determined as follows: following to the production and casting of concretes, they were kept under plastic cover for 24 hours. Next, concretes to be air cured were demoulded and watered in the morning and evening for a week and then they were kept in laboratory conditions (temperature of 23 ± 5 °C and relative humidity of 55 ± 10 %) up to the experiment day. In moisture curing, beams were demoulded by a crane and burlap rolled onto them thereafter, continuous wetting was provided for 2 weeks. Then, the beams were kept in the laboratory until the experiment day.

In the study, the concrete mixtures were designated with the following codes: first letters represent the concrete type, while the next two digits and the final letter show the concrete strength class and the curing medium (M for moisture and A for laboratory (i.e. air) medium), respectively. For example, CC25A represents CC with a strength class of C25 cured in air.

C. *Mix Design, Production of Concrete and Reinforced Concrete Beams and Coring*

Mixture proportions of the SCC and CC produced for the reinforced concrete beams are given in Table 3. Experiment results of fresh concrete of CC and SCC are given in Table 4.

Concretes were produced in concrete mixer with a capacity of 250 dm^3. During the production, after mixture water with chemical additive, which is hyper plasticizer for SCC and super plasticizer for CC, and cement were added to the concrete mixer, premixing was performed for 2 minutes. Then, coarse (4/8, 8/16) and fine aggregates (0/2, 2/4) were added and mixing was continued for 2 minutes. Finally, fly ash and filler (for only SCC) was added and mixing was

TABLE 3. Mixture proportions of concretes

	C25/30				C50/60				C70/85			
	CC		SCC		CC		SCC		CC		SCC	
	Weig.	Vol.	Weig.	Vol.	Weig.	Vol.	Weig.	Vol.	Weig.	Vol.	Weig.	Vol.
Cement	275	88.7	275	88.7	350	112.9	350	112.9	425	137.1	425	137.1
Fly ash	41	18.8	41	18.8	52.5	24	52.5	24	64	29.1	64	29.1
Filler	-	-	60	21.9	-	-	75	27.3	-	-	90	32.8
Water	231	230.8	226	225.7	221	221.3	215	214.9	205	205.3	214	214.1
Super Plas.	-	-		-	5.25 (%1.5)	4.5	-	-	10.63 (%2.5)	9.16	-	-
Hyper Plas.	-	-	1.375 (%0.5)	1.32	-	-	2.63 (%0.75)	2.5	-	-	4.25 (%1.0)	4.01
Air content	-	10	-	10	-	10	-	10	-	10	-	10
Aggregate 0/2	408.9	162.9	477	190	393.5	156.8	458	182.5	382.3	152.3	431.2	171.8
Aggregate 2/4	421.9	162.9	410	158.3	406.1	156.8	393.9	152	394.5	152.3	370.8	143
Aggregate 4/8	451.2	162.9	438.7	158.3	434.3	156.8	421.3	152	421.9	152.3	396.6	143
Aggregate 8/16	425.2	162.9	330.6	126.7	409.2	156.8	317.5	121.6	397.6	152.3	298.9	114.5
Total	2254	1000	2260	1000	2272	1000.5	2286	999.5	2301	1000	2295	1000
Water/Binder	0.73	-	0.72	-	0.55	-	0.53	-	0.42	-	0.44	-
Water/Powder	-	-	0.60	-	-	-	0.45	-	-	-	0.37	-

Notes: 1- The unit of all weights is kg while unit of all volumes is dm^3
2- Values in the brackets show ratio of chemical additive material.

TABLE 4. Experiment results of fresh concrete of SCC and CC.

	CODE	Unit weight (kg/m^3)			Slump (cm)	Slump flow (cm)
		Measured	Theoretical	Difference(%)		
1	C25/30 CC	2260	2254	0.3	20	-
2	C25/30 SCC	2278	2260	0.8	-	65
3	C50/60 CC	2272	2272	0.0	21	-
4	C50/60 SCC	2309	2286	1.0	-	67
5	C70/85 CC	2314	2301	0.6	23	-
6	C70/85 SCC	2316	2295	0.9	-	74

continued for 4 minutes, in other words total mixing was finished in 8 minutes.

Beam dimensions were determined to be 200x250x3000 mm. Rebar of the beams were calculated as 2ø12 for the top and 3ø12 for the bottom. Stirrups ø8 were used as lateral rebar at the beams and stirrup distances were chosen as 10 cm in the confinement zone and 15 cm at the central zone. In this manner, densification of rebars in lateral cross-sections of beams and handling of SCC in real conditions were aimed. Fig. 1 (a) shows schematic drawing of the rebars. Concrete covers of the rebars were chosen to be equal in all directions as 25 mm. In situ realization of concrete covers was provided by using plastic concrete cover apparatus.

Different methods were used in placement of concretes to the beams according to the concrete type. After placement of CCs to the beams, they were vibrated at intervals of 25 – 30 cm by using a laboratory type vibrator and their upper surfaces were finished by a steel trowel. During the moulding of SCC, a wooden prismatic rabbet was used to cast the concrete from the concrete mixer to one end of a formwork. Therefore, in components with SCC, concrete was poured from one end of the formwork and traveled through it by itself up to the other end (300 cm) and after complete placement; the upper surface of it was smoothened by a steel trowel. In this way, the effect of rebars and surface of a formwork on the movement of SCC and, therefore, whether there is a difference between one end and the other

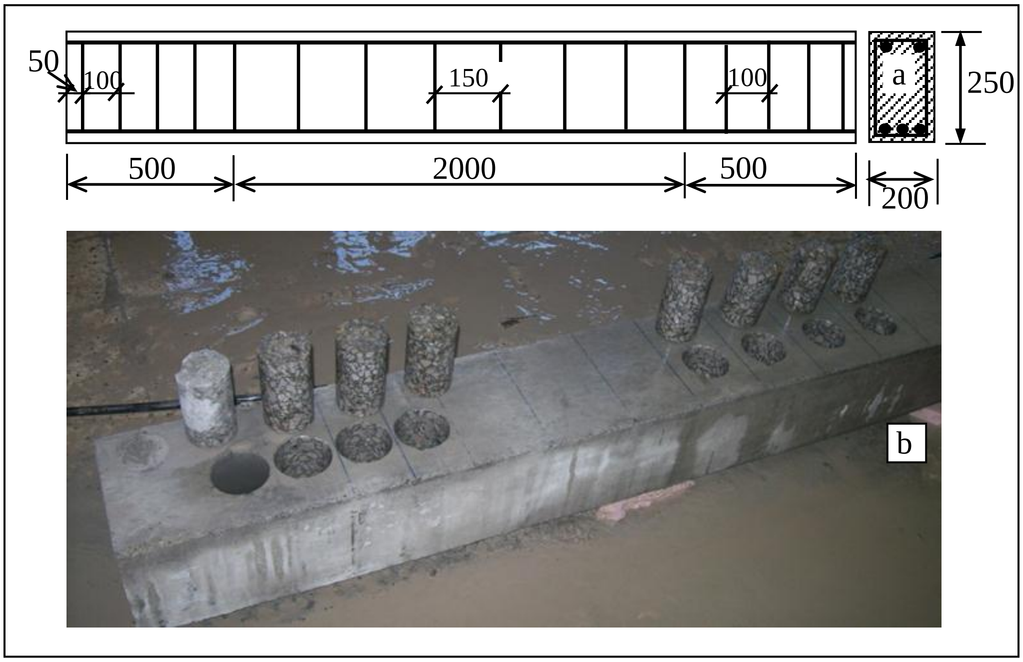

Figure 1 (a). Dimensions of the beams, rebar detailing (not drawn to scale, dimensions are in mm), (b). Core samples taken from a reinforced concrete beam

end of a beam in terms of AVPV rates and homogeneity or not will be determined.

Before core samples were taken from the beams, the positions of the rebars at the beams were determined by using a microcovermeter. Core samples of ø8x5 cm were taken from the beginning (0-100 cm), middle (100-200 cm) and end (200-300 cm) zone of the beams according to the casting direction of SCC, see Fig. 1 (b). Besides, core samples were also taken from the side surfaces of the beams touching to the formwork. As it was pointed out by Isgor and Razaqpur [33], cracks formed on the upper parts of the components and especially shrinkage has an important effect on the transport properties of the concrete.

D. *Procedure of permeable voids rate determination experiment in hardened concrete*

Permeable voids rate determination experiment in concrete was carried out on the cylindrical samples having a diameter of 8 cm and height of 5 cm, according to TS 3624 [34] on the 28th day. Samples have been kept inside water which is at 23±2^{o}C during 2 days before the experiment. After this pre-conditioning process, experiment samples were weighed and dried for 24 hours in drying oven which is at 105±5^{o}C. Dry weight (A) of the samples that were taken out from drying oven and reached a constant weight was determined by weighing them in air. After the samples whose drying oven dry weights were determined have been cooled up to 20±5^{o}C, they were submerged into water at 21±2^{o}C and kept there for 24 hours. After surface wetness of the samples which were taken out from water at the end of this period was removed by the help of a towel, they were again put into water for 24 hours and re-weighed after this duration. The last weighing value where the difference between these two successive weighing is less than 0.5% was recorded as saturated, dry-surfaced sample weight (B). Next, samples were placed in a boiling pot and pot was filled with water until all samples are submerged into water. Samples have been boiled for 5 hours, and they were left for cooling at room temperature until their temperature decreases to 20-25^{o}C providing not to wait less than 14 hours, and then they were weighed (C) after they were taken out from the pot. Weight of the boiled, saturated dry-surfaced experimental sample (D) in water was determined in mean time. Apparent volume of permeable voids (B_0) of the samples was calculated by putting these obtained values into the (1) given below.

$$B_0 = [(C - A)/(C - D)] \times 100 \qquad (1)$$

III. *Research findings and discussions*

Variation of the AVPV experiment results conducted on CC and SCC's with respect to concrete type, concrete class and curing condition are given in Fig. 2. Each value is the average of three samples.

It is seen from Fig. 2 that mean AVPV values of core of same concrete type but having different concrete class are different than each other depending on curing conditions. According to this, for air curing, the decrease rates in C50 and C70 concretes with respect to C25 concrete class in CC's are 16% and 35%, respectively; and again 16% and 37%, respectively in SCC's. In moisture curing, the decrease rates in C50 and C70 concretes with respect to C25 concrete class in CC's are 16% and 38%, respectively; and again 19% and 43%, respectively in SCC's. As seen; while decrease of apparent volume of permeable voids (AVPV) with increasing concrete class in air curing is almost in same rates in CC and SCC's, decrease rates in SCC's are higher than the one in CC's in moisture curing. Accordingly, it was concluded that sensitivity of SCC against curing is greater.

Main factor that makes apparent volumes of permeable voids decrease with increasing strength of concrete is W/B ratio. In concrete technology, it is known that volume of voids in concrete increases with increasing W/B ratio. As seen from Table 3; W/B ratios of SCC and CC's are almost same (around 0.73 for C25 concretes, 0.54 for C50 concretes, and 0.43 for C70 concretes). As seen; W/B ratios of the concretes whose apparent volume of permeable voids is low are also low. It was also stated in Safiuddin and Hearn [35] that W/B ratio greatly influences porosity of the concrete. Reason for the effect of W/B ratio is because it alters void structure of the concrete. Firstly, diameter of critical pore increases with the increase of this ratio. In other words; void structure becomes coarse as long as quality of concrete decreases and accordingly maximum pore diameter which is known as threshold pore diameter increases [22, 24]. This results in increase in concrete's porosity.

High concrete dosage, accordingly the higher amount of fly ash and limestone filler which are other two constituents determined by the rate of concrete dosage could cause C70 concrete to have smaller AVPV ratio than other concrete classes. Excess of the amount of these constituents also makes W/B ratio reduced. On the other hand, it can be said that cement grains which are not hydrated increase the compactness of concrete by behaving as filler material. Moreover; it should not be forgotten that pozzolan material could form filler effect in concrete [36]. Again, usage of fly ash generally provides obtaining a more dense internal structure by decreasing micro cracks in interfacial zone [37], the thickness of inter-surface region [38], and pore dimensions in concrete [39, 37]. In addition to these, fly ash decreases water demand, segregation, hydration heat, amount of shrinkage of the concrete and bleeding in fresh concrete [9, 39, 40, 41, 15]. Furthermore; workability of the concrete develops because stability, easy filling and squeezing of the fresh concrete are provided through sphericity of fly ash particles [39, 15]. In this study, all of these positive influences of fly ash might cause decrease of void rate within the concrete.

Other researchers (for instance; references [42], [43] and [44]) also stated that high strength concrete is more compact with respect to normal concrete and volume of permeable voids in concrete decreases with increasing concrete compressive strength. However; it was determined in a study conducted by Assie *et al*. [5] that porosity of SCC mixtures is slightly higher than CC's regardless of strength class. This conclusion is linked to the condition that higher W/C ratios were used in SCC with respect to CC in the study.

Again from Fig. 2**,** AVPV ratios of concretes which have same concrete class but different types vary depending on both concrete class and curing condition. As a matter of fact; it was determined that SCC ones of C25 and C50 concretes which were kept in air cure have 7 % less AVPV ratio than CC's and SCC ones of C70 class have 10 % less AVPV ratio than CC's. For moisture curing, SCC's have 5%, 9%, and 13% less AVPV ratios than CC's for C25, C50, and C70 classes, respectively. As seen, SCC's have less permeable void rates than CC's in same class for both curing condition. It must be particularly stated that this difference becomes more distinct with increasing strength value of the concrete in moisture curing. Maximum difference was seen in concretes of C70 class kept in moisture curing. In other words, SCC ones have 13 % less void rate than CC's between the concretes whose 28 day-compressive strength values are 70 MPa and kept in same moisturized condition.

It could be because of the filler (powder material) used in SCC mixtures that SCC's have less volume of

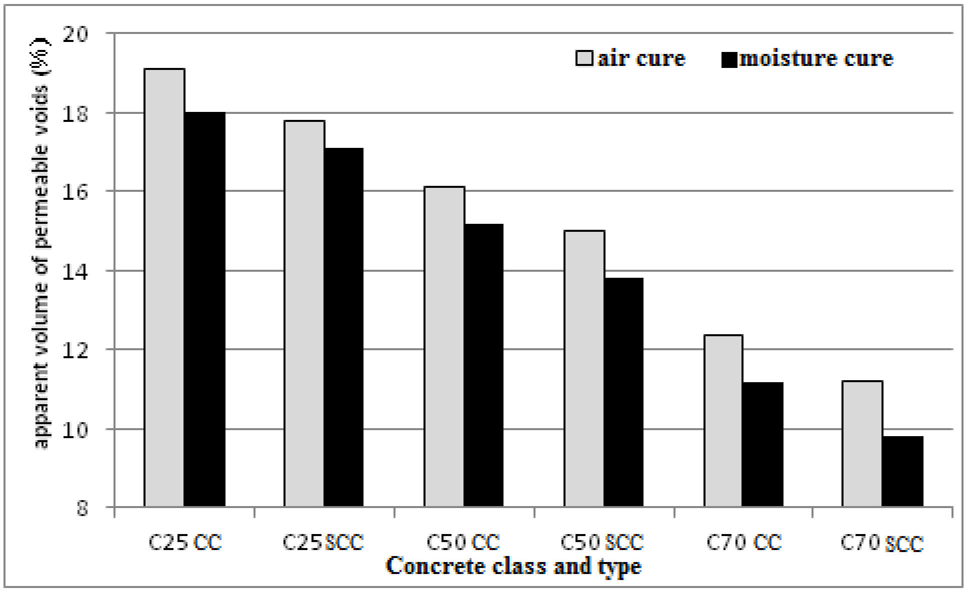

Figure 2. The variation of volume of permeable void with respect to curing condition, concrete class, and concrete type

permeable voids than CC's. As also seen from Table 3; limestone filler of 21% was added to SCC's unlike CC's. Filler material could cause denser matrix formation since it fills some sections of the voids between cement particles which are normally filled with water. In other words, compactness of the granular composite (concrete) was increased by extending particle size distribution of the solid particles which form distributed phase with filler material, and accordingly formation of thinner void-structure could be obtained.

A similar type of approach given above was also exhibited in Valcuende and Parra [22]. However; in their studies researchers stated that entrained air volume remained in SCC is greater compared to CC. It was claimed that this situation is caused by the SCC which has longer mixing duration, higher amount of plasticizer, and in particular higher amount of thin particles. Researchers have the thought of thin material in suspension forms a network which prevents bubbles to go upper surface of the sample and to be evacuated. Nevertheless; it was stated that volume of entrained air constitutes a small amount of total pore volume and accordingly its effect on physical and mechanical properties of the material will remain at a low level.

From the graph in Fig. 3 which was drawn by using mean AVPV values obtained in this study, volume of permeable voids in SCC concretes decreases as long as dosage of the limestone filler used increases for both curing condition. Also in the study that was conducted by Ye *et al*. [21] and limestone powder was used as filler material, it was determined that SCC mortars have less total void volume among self-compacting, high performance, and conventional concretes according to results of mercury intrusion porosimetry (MIP) measurement.

However; unlike CC, not applying vibration process to SCC prevents to occur some risks such that excessive vibration causes bleeding and segregation or insufficient vibration results in increase of entrapped air voids inside the concrete [45, 46, 22]. Furthermore; as a result of vibrating concrete, accumulation of space water on interfacial zone can also cause to increase in porosity [46]. From this information, it is concluded that SCC has less total void volume than CC possibly because of not applying vibration process during SCC production.

On the other hand, cement-aggregate interface in concrete has a more porous structure than cement paste [47, 11]. Reason for this is the micro cracks which form on aggregate-cement interface and which are also considered as void system of the concrete [48]. Several factors determine the properties of interfacial transition zone. For instance; width [45] and porosity [46] of interfacial transition zone increase with increasing W/B ratio and aggregate/cement ratio. Void volume in interfacial transition zone in SCC is smaller than CC because both W/B ratio and amount of coarse aggregate are less in SCC. In addition to these factors, powder materials used in SCC contribute to the interface to have denser structure by forming filler effect [49, 50].

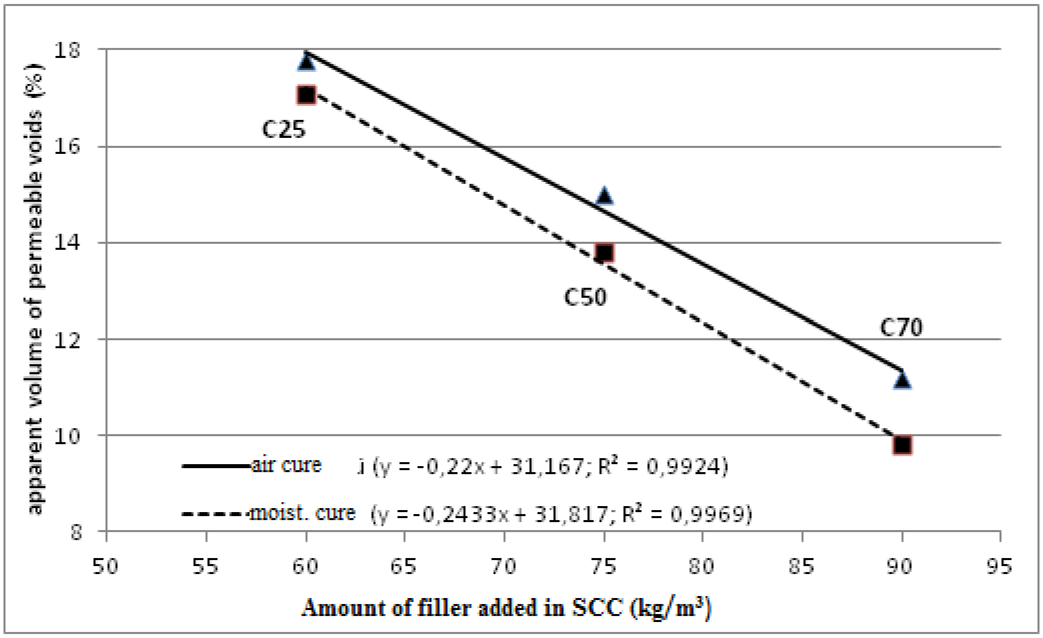

Figure 3. For air and moisture cures, the effect of the amount of the limestone filler used in SCC on apparent volume of permeable voids

Nevertheless; it was seen that AVPV ratios vary with same type concretes of same strength class when concretes keep in different curing conditions. Accordingly; as C25, C50, and C70 classes of CC's have 6%, 6%, and 10% less AVPV ratios, respectively if they are kept in moisture curing with respect to air curing condition; these ratios are to be 4%, 8%, and 13% respectively for SCC's. From these ratios; even for the same concrete type, it can be concluded that curing condition has influence on void ratio of concrete and the level of influence increases as strength class increases. Again, it is concluded that curing condition for SCC is more significant particularly in the concretes having high strength.

This situation can be explained as percentage of occurrence of hydration reactions is higher in concretes where moisture curing is applied with respect to the ones where air curing is applied. Because; amount and size of the capillary voids are greater at the first stage of cement hydration reaction. However; hydrated products (particularly C-S-H) which appeared as a result of the reaction which cement did with water fill capillary voids and this incident continues as long as sufficient moisture exists in environment [11]. Increase of hydration degree enables hydration products to fill more amounts of voids [46] and accordingly causes decreases in volume and size of capillary voids in concrete, and makes voids disconnected to each other [51]. If it is thought that especially 80-90% of porosity seen in concrete is composed of capillary void volume [52], the importance of hydration reaction could be understood better. On the other hand; problem of non-existence of the required water for hydration happens because of evaporation of water in concrete in case of absolute moisture decreases below 80% in the environments where hydration occurs. Water loss is more significant particularly in first days of maturation because hydration is much more and faster. Absolute moisture will have a remarkable contribution to the controlled hydration of concrete in hardening period [18].

Besides; in the samples which moisture curing is applied, it needs to be stated that formation of additional C-S-H gels as a result of pozzolanic reactions which occur between fly ash and $Ca(OH)_2$ of hydrated cement in watery environment can cause decrease in the amount of void within concrete.

From this point; it can be said that samples which insufficient curing (air curing) is applied to in the study contains voids of greater volume and size and their porosity becomes higher because of the reasons such that hydration reactions cannot be completed, pozzolanic activity could not reach to the required level, and additional voids caused by water evaporation. This result means that moisture curing will positively develop the amount and structure of voids of concrete with respect to air curing, also concretes are required to be sufficiently cured in case of concretes having lower porosity are desired.

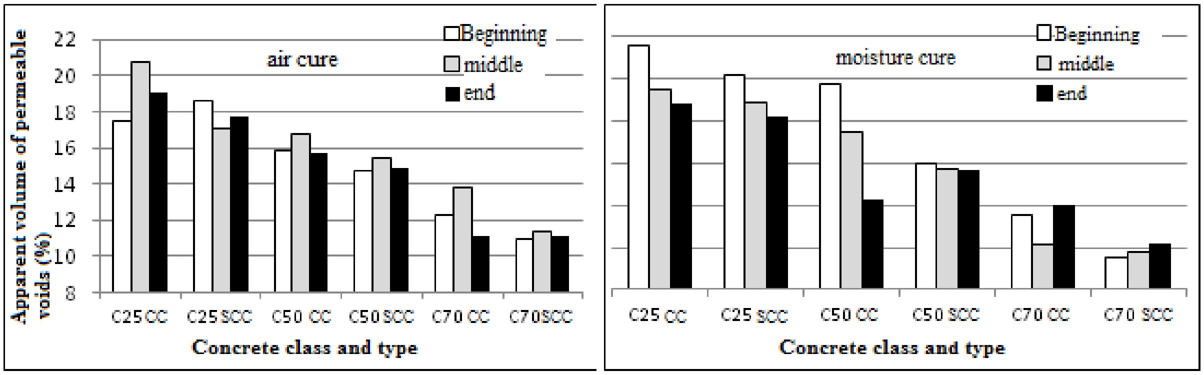

Figure 4. Variations of AVPV ratios of cores obtained from beginning, middle, and end sections of the beams due to concrete class, type of concrete, and curing condition

One of the purposes of this study is to compare CC and SCC in terms of uniformity based on AVPV experiments. To achieve this, AVPV ratios (Figure 4) measured on the cores which were obtained from three different locations of the beams (beginning, middle, and end) and subjected to the experiment were used. As also seen in Fig. 4; AVPV ratios in the beams produced with CC have more distant values than the ones produced with SCC. This situation is more apparently seen from standard deviations of the values given in figures. Thus; standard deviations of C25, C50, and C70 concretes of CC and SCC cured in air have value pairs of (1.7;0.8), (0.6;0.4), and (1.4;0.2), respectively (first value belongs to CC, second one belongs to SCC). Whereas; standard deviations of C25, C50, and C70 concretes of CC and SCC cured in moisture have value pairs of (1.5;1.0), (2.8;0.2), and (1.0;0.4), respectively. As seen; for all concrete classes, variations in SCC are in very less level with respect to CC. Therefore; it is possible to say that SCC is more uniform than CC in terms of volume of permeable voids rates. It can be seen from the corresponding graphs and as well as from standard deviations that uniformity of SCC becomes more obvious as strength class increases.

IV. *Results*

Obtained results within this study are summarized below:

- For same concrete class; it was seen that SCC's have less permeable void ratio than CC's. SCC ones of C25, C50, and C70 concretes kept in air cure have 7%, 7%, and 10% less AVPV ratios than CC's, respectively; SCC ones of C25, C50, and C70 concrete classes kept in moisture cure have 5%, 9%, and 13% less AVPV ratios than CC's, respectively.

- Keeping concretes in different curing conditions affects the increase in permeable void ratios. AVPV ratios of all concretes decrease in moisturized condition. For C25, C50, and C70 classes; it was seen that as CC's kept in moisture curing have 6%, 6%, and 10% less AVPV ratios than the ones kept in air curing, respectively; these ratios are to be 4%, 8%, and 10% respectively for SCC's.

- It was observed that AVPV ratios decrease as concrete strength class increases regardless of concrete type. For air curing; AVPV ratios of C50 and C70 concretes are 16% and 35% less than C25 concrete class, respectively in CC's; and again 16% and 37% less, respectively in SCC's. Whereas in moisture curing; AVPV ratios of C50 and C70 concretes are 16% and 38% less than C25 concrete class, respectively in CC's; and again 19% and 43% less respectively in SCC's. These ratios show that the decrease in permeable void ratio almost takes place at the same rate in CC and SCC with increasing concrete class cured in air; despite that, decrease rates in SCC is greater than CC's in moisture curing. Again from this point; it can be concluded that sensitivity of SCC against curing is greater.

- SCC's having less volume of permeable voids than CC's can be correlated to the volume of void of SCC's interfacial transition zone being less than CC's, usage of filler and not applying vibration process in SCC unlike CC.

- The decrease in the AVPV ratios of the concretes with increasing compressive strength is explained by the increase in the strength of the concrete, the reduction in the

W/B ratio in SCC and CC and the increase in the cement content as well as the amount of fly ash.

- When standard deviations for AVPV ratios of the cores obtained from beginning, middle, and end points of CC and SCC beams are taken, for each concrete class; it was seen that variation in SCC is at very low level with respect to CC. Therefore; it was concluded that SCC displays a more uniform character than CC. In the study it was found extremely significant in terms of the performance of concrete elements under load and environmental effects that concretes which placed with self weight in the beam which ductility level was developed (that is with dense reinforcement) along 300 cm, displays more uniform characteristic than the concretes compacted with vibrator. Because it means that this situation prevents reinforced concrete elements to behave differently from each other under service loads and external loads like earthquake, and also means that it prevents the formation of local weak regions in concrete elements/structures in terms of durability.

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In this study comparison of Self compacting concrete and Conventional concrete were carried out.

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