

# EFFECT OF FLY ASH ON SHRINKAGE OF SELF-COMPACTING CONCRETE USING RESTRAINED RING TEST

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## **Abstract**

In recent years, fly ash (FA) has been increasingly used widespread like a mineral admixture for the production of concrete in general and self-compacting concrete (SCC) in particular. Fly ash is an industrial by-product and is generated during the combustion of coal for energy production from the thermal power station. Fly ash is utilized to increase the workability of concrete mixtures and increase shrinkage resistance of the self-compacting concrete. In this paper, the mixture design of the self-compacting concrete with strength grade of 60 MPa is performed with requirement that the workability satisfies the slump flow,  $T_{500}$  and the V-Funnel  $T_V$  test range from 650 to 800 mm, from 2 to 5 s and from 6 to 12 s, respectively. Besides, fly ash is used to replace cement with content of 15%, 25%, 35% and 50% to evaluate shrinkage resistance. The obtained results showed that using fly ash contents from 25% to 35% to replace cement can ensure workability of the mixture together with high degree of shrinkage restraint. According to ASTM C1581, the evaluation of restrained shrinkage of the self-compacting concrete based on the restrained ring test, this method reduces the testing time but still ensure the reliability.

*Keywords:* fly ash; self-compacting concrete; shrinkage resistance; restrained ring test.

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## **1. Introduction**

In the rapid urbanization, the civil and industrial construction, roads and bridges, port structures have been increasingly expanded and developed. As a result, there are many constructions with complex structural forms that require high load capacity along with the density of thick reinforcement resulting in the vibration of concrete mixes difficult to implement. Therefore, it is necessary to have a typical concrete with high flow ability and self-compacting characteristic based to its own weight (without vibration). The concrete must also not stratified by water separation. The self-compacting concrete (SCC) highly meets these requirements and has several advantages of good workability. But the SCC still has a number of issues that can greatly affect the quality of the structures. The shrinkage distortion in the SCC is more significant than the traditional concrete.

According to [1], shrinkage strain in concrete is the process of changing the volume due to the loss of moisture from the stage of fresh concrete mixture until the hardening process. This volume change is affected by internal and external factors which can occur simultaneously or independently. The shrinkage of concrete is classified into five types as follows: plastic shrinkage, carbonation shrinkage, autogenous shrinkage, thermal shrinkage and dry shrinkage.

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According to [2], in order to investigate the shrinkage of SCC, the amount of fly ash content replaced the amount of cement by 35%, 55% and 65%, respectively. In each case of replacement, concrete was cast and moisturized in six circular cylindrical samples with dimension of 75 mm × 225 mm. Specifically, the first three samples were used to measure dry shrinkage and the remaining three samples were used to measure spontaneous shrinkage. Experimental results show that by using fly ash, the content of cement and water content decreases resulting in stronger concrete. Moreover, the mixture containing 65% fly ash has the lowest dry shrinkage and autogenous shrinkage.

In structure, the components connected with each other which have different shrinkage, will cause the contraction of shrinkage between them. As a result, the tensile stress arises to resist the shrinkage strain of concrete. Then the tensile stress develops in the structure, if it exceeds the tensile strength of concrete, cracking will occur [3]. For many years, engineers have used ASTM C157 to test the free shrinkage strain of concrete by changing the length of the sample [4]. However, the parameters of free shrinkage strain are not strong enough to predict the time in which cracking appear, because the cracking resistance depends on many factors such as shrinkage rate, elastic modulus of concrete, stress relaxation, creep and shrinkage resistance [5].

Currently, the restrained ring test is widely used to evaluate the cracking resistance due to its accuracy, time saving and lower test costs. AASHTO P34 [6] and ASTM C1581 [7] are two commonly used restrained ring test standards.

There are many studies related to the investigation of the cracking resistance of self-compacting concrete. According to [8], the age of cracking according to ASTM C1581 is from 15 to 18 days lower than AASHTO P34. This shows that the growth stress rate in ASTM C1581 is higher than that of AASHTO P34. In addition, the analysis of stress distribution in the restrained ring test shows that the cracking trend of ASTM C1581 is derived from the inner surface of the concrete ring spreading to the outside and AASHTO P34 is reverse.

In this paper, the author investigates the shrinkage resistance for SCC according to ASTM C1581 by using fly ash content to replace cement content of 15%, 25%, 35% and 50% by weight, respectively. The mixture design for self-compacting concrete with strength grade of 60 MPa, the slump flow test,  $T_{500}$  test, V-funnel test with required the slump flow value from 650 to 800 mm,  $T_{500}$  from 2 to 5 s and  $T_V$  from 6 to 12 s.

## 2. Materials and experimental program

### 2.1. Materials

In this study, the mixture design with strength grade of 60MPa which has total powder of 530 kg, including the OPC cement of Nghi Son cement (C), fly ash (FA) of Duyen Hai thermal power plant with the type F varying from 0% to 50% by cement weight and 6% silica fume of Elkem (SF). The fine aggregates including river sand from Dong Nai River (RS) and crushed sand from Tan Cang quarry (CS), coarse aggregate from Tan Cang quarry (CA) at maximum size of 12.5 mm. ROADCON-SR500F superplasticizer (SP) admixture is used with the dosage of 1.45% of total powder to increase the workability and to modify the viscosity of the concrete mixture (Fig. 1).

The process of design self-compacting concrete in research is in compliance with the ACI 237R-07 (2007) [9] with absolute solid volume principle. The proportion of materials for producing five mixes of SCC is given in Table 1. These percentages of fly ash are calculated on the basis of the total weight of cement plus fly ash.



Figure 1. Raw materials used in this research

Table 1. Volume of raw materials of the mixture design

Mixture design	C (kg)	FA (kg)	SF (kg)	RS (kg)	CS (kg)	CA (kg)	SP (kg)	W (kg)
SCC-FA-0	508	0	32.4	562	306	724	7.83	205
SCC-FA-15	427	81	32.4	571	311	735	7.83	189
SCC-FA-25	373	135	32.4	569	310	733	7.83	184
SCC-FA-35	319	189	32.4	567	309	730	7.83	179
SCC-FA-50	238	270	32.4	561	306	723	7.83	174

In the study, all of the mixes are prepared in the laboratory. Tests are carried out in accordance with the standard method used for determining physical properties of SCC mixture and restrained shrinkage test in Table 2.

Table 2. Standard test methods used in the study

No	Properties	Unit	Limit Requirements	Test method
1	Slump flow	mm	650 – 800	BS EN 12350-8:2010 [10]
2	$T_{500}$	s	2 – 5	BS EN 12350-8:2010 [10]
3	$T_V$	s	6 – 12	BS EN 12350-9:2010 [11]
4	Compressive strength	MPa	60	TCVN 3118:1993 [12]
5	Restrained shrinkage			ASTM C1581 [7]

## 2.2. Experiment process

Given that the main parameters that influence the shrinkage resistance of SCC contains FA include the proportion of fly ash, the mixes process, the curing conditions and the current testing regime was

designed to target these factors. The raw materials were added to the mixture and mixed following the defined process according to the corresponding time in Table 3 and Fig. 2.

Table 3. Concrete mixing process to prepare specimens

Step	Content	Mixing time
1	Adding 100% Coarse aggregate + 100% Binder + 100% crushed sand	1 minute
2	Adding 40% (water + admixture)	2 minutes
3	Adding 40% (water + admixture)	2 minutes
4	Adding 100% River sand	2 minutes
5	Adding 20% (water + admixture)	3 minutes
6	Finish the mixing process	

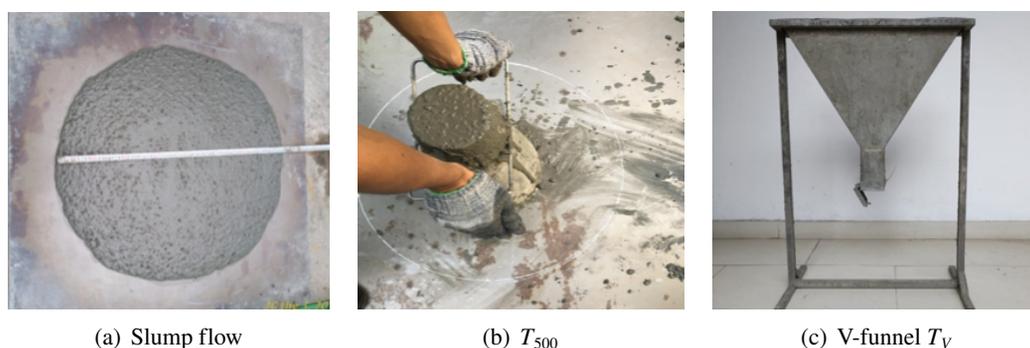


Figure 2. The measurement of workability of SCC specimens

When the concrete mixture has met the requirements of workability, cube samples were cast for the compressive strength test and the restrained ring test were performed. The experiments of the shrinkage resistance by assessing potential for cracking classification with different fly ash content through two parameters obtained from the experiment, age at cracking  $t_{cr}$  and average stress rate  $S$  were carried out.

In the restrained ring test, the steel strain value was recording by the data collection system through connecting the strain gauge with computer to store the data. Monitoring and recording steel strain value is performed with one-hour frequency.

The process of conducting experiments to evaluate the shrinkage resistance of SCC is shown in detail in Fig. 3. Using wet burlap layer and polyethylene film to cover the specimens in curing condition can control the water evaporation and minimize original plastic shrinkage of SCC. According to [13], the period of plastic deformation occurred from four to five hours under humid conditions and from six to seven hours under dry conditions.

### 3. Test results and discussions

#### 3.1. Workability evaluation of self-compacting concrete

The workability of self-compacting concrete mixture was measured by slump flow,  $T_{500}$  and  $T_V$  tests. The results of the workability experiment are shown in Table 4 when the fly ash content was replaced from 0% to 50%, respectively.



Figure 3. The experimental process of restrained ring test

Table 4. Workability experimental results

Mixture design	Slump flow (mm)	$T_{500}$ (s)	V-funnel $T_V$ (s)
SCC-FA-0	655	4.42	8.53
SCC-FA-15	690	2.44	7.42
SCC-FA-25	750	1.47	5.56
SCC-FA-35	780	1.20	4.26
SCC-FA-50	800	1.02	3.05

It can be seen that most of the samples are within the allowable range and meets the required slump flow value from 650 to 800 mm,  $T_{500}$  from 2 to 5 s and  $T_V$  from 6 to 12 s. In particular, experimental results indicate that slump flow test was increased from 655 to 800 mm corresponds to the content of fly ash replacing the cement content increased from 0% to 50%. However, results of  $T_{500}$  and V-funnel  $T_V$  reduce gradually from 4.4 to 1.02 s and from 8.53 to 3.05 s, respectively. Especially, the mixes, using up to 50% fly ash content, has a phenomenon of segregation and bleeding.

Workability tends to increase as fly ash content increases because fly ash is spherical, fine-grained with a particle diameter of 1  $\mu\text{m}$  to 50  $\mu\text{m}$  to improve the overall particle size distribution, creating a coating covering aggregate particles in concrete mixes for easy sliding on each other. In addition, it reduces the internal friction between particles and reduces the plastic viscosity. Therefore, the workability of the concrete mixture was increased.

### 3.2. Influence of fly ash on the restrained shrinkage of self-compacting concrete

The strain evolution of the ASTM C1581 ring specimens with FA at different proportions is shown in Fig. 4. The results clearly indicate that increasing the percentage of fly ash in SCC samples makes positive influence on the cracking potential of all samples tested. As the fly ash content from 25 to 50% replacement the age at cracking increased by 14.28 and 18.98 days. Regarding 50% fly ash replacement the age of cracking is significantly higher than any other tested sample. Especially, the age of cracking of 15% fly ash replacement was lower than the control sample. The reason for this phenomenon is that the fly ash replacement content can help separate cement particles and they can hydrate quicker than mixture without fly ash. In addition, the adjustment of the concrete mix to achieve the required about workability and compressive strength has also affected the results; thus, increasing the fly ash content replacement cement has led to the reduction of water content in the mixture and can increase the hydration process rate.

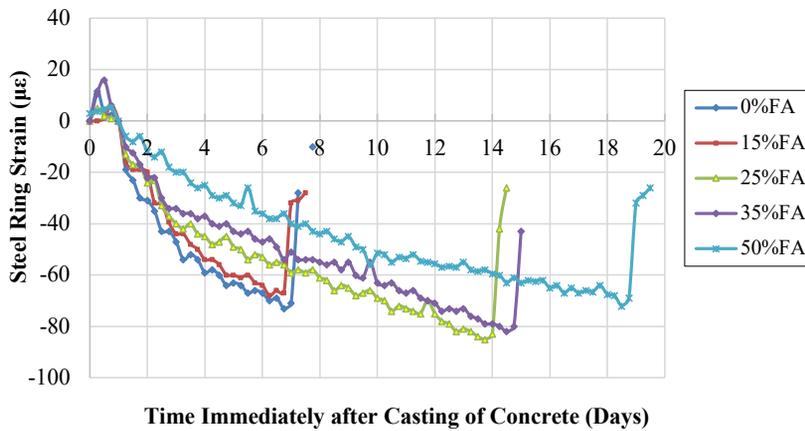


Figure 4. Steel ring strain and time for fly ash SCC mixes

The average tensile stress ( $\sigma_{c\_avg}$ ) is calculated according to [14] based on the mechanical equilibrium between the steel and concrete rings in the concrete ring specimens, presented below:

$$\sigma_{c\_avg}(t) = \frac{E_{st}r_{ic}h_{st}}{r_{is}h_c}\varepsilon_{st}(t) = G\varepsilon_{st}(t) \quad (1)$$

where  $G$  is a constant for the ring setup (72.2 GPa for the geometry follow to ASTM C1581);  $E_{st}$  = 200 GPa is the modulus of elasticity of the restrained steel ring;  $h_{st}$  and  $h_c$  are the wall thicknesses of the steel and concrete, respectively;  $r_{is}$  and  $r_{ic}$  are the internal radius of the steel and concrete, respectively; and  $\varepsilon_{st}$  is the strain in the steel ring.

Fig. 5 shows the average tensile stress ( $\sigma_{c\_avg}$ ) values in concrete specimens due to shrinkage by time. When increasing the fly ash content to replace cement from 0 to 50%, the average tensile stress values gradually decreased with the replacement content respectively at the same time of the survey. The reason for this is that fly ash reduced shrinkage in concrete leading to reduced tensile stress. Therefore, cracking in ring specimen depends on the average tensile stress rate. In fact, the relationship between the age at cracking and the average stress rate shows that the higher the stress rate, the shorter the time it causes cracks simply.

The levels of potential for cracking can be assigned to each mixture based on the classification table in the appendix section of ASTM C1581 and as shown in Table 5.

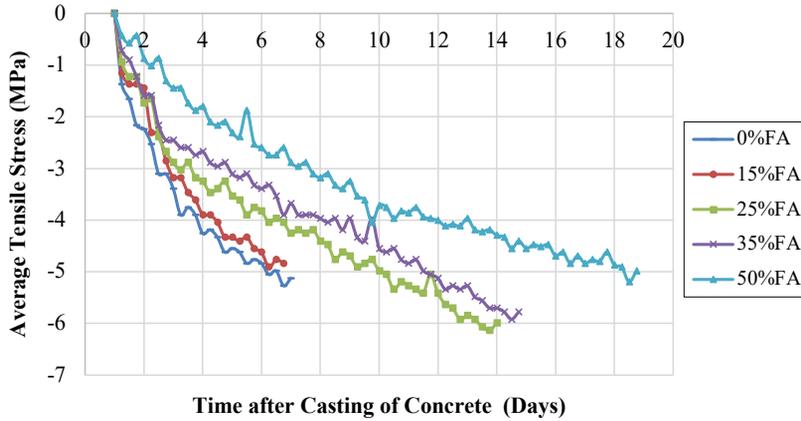


Figure 5. The average stress due to shrinkage of SCC by time

Table 5. Potential for cracking classification

Time-to-cracking, $t_{cr}$ , days	Stress rate at cracking, $S$ , (MPa/day)	Potential for Cracking
$0 < t_{cr} \leq 7$	$S \geq 0.34$	High
$7 < t_{cr} \leq 14$	$0.17 \leq S < 0.34$	Moderate-High
$14 < t_{cr} \leq 28$	$0.10 \leq S < 0.17$	Moderate-Low
$t_{cr} > 28$	$S < 0.10$	Low

The degree of shrinkage resistance of SCC is presented by cracking potential classification. The potential for cracking were depended on the age at cracking (time-to-cracking) and the average stress rate which were affected significantly by proportion of fly ash as shown in Table 6.

Table 6. Age at cracking for control and fly ash SCC mixes

Mixture design	Age at Cracking (Days)	Average Stress Rate (MPa/day)	Potential for Cracking
SCC-FA-0	7.13	0.43	High
SCC-FA-15	7.05	0.47	High
SCC-FA-25	14.28	0.23	Moderate-High
SCC-FA-35	15.04	0.21	Moderate-High
SCC-FA-50	18.98	0.16	Moderate-Low

The experiment results indicate that fly ash can be used to replace the cement up to 50% with significant improvement in the potential for cracking for the mix at moderate-low. In particular, with using fly ash content from 25% to 35%, SCC has potential for cracking at moderate-high.

#### 4. Conclusions

This research investigated the degree of shrinkage resistance for the self-compacting concrete mixes using various FA contents to partially replace the cement. The results reveal the following:

Self-compacting concrete with a higher fly ash content as cement replacement tend to increase the workability of SCC mixture. In particular, fly ash content of 25% and 35% significantly improved

the workability of the mixture. But fly ash replacement of cement by up to 50% has appearances of segregation and bleeding.

The restrained ring test results according to ASTM C1581 showed that fly ash using up to 50% significantly improved shrinkage resistance of SCC. Based on the experimental results, the optimal fly ash contents were proposed from 25% to 35% ensuring workability of mixture and having high degree of the shrinkage resistance.

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