

# PROPRIETĂȚILE MECANICE ȘI CONTRACȚIA LA USCARE A BETONULUI AUTOCOMPACTANT CU ADAOS DE CENUȘĂ MECHANICAL PROPERTIES AND DRYING SHRINKAGE OF SELF-COMPACTING CONCRETE CONTAINING FLY ASH

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*Self-compacting concrete (SCC), also known as self-consolidating concrete, can be classified as an advanced construction material. SCC is a highly flowable concrete that can achieve full compaction without the need of vibration. In this study, the influence of fly ash on workability, mechanical properties and drying shrinkage of SCC specimens were investigated. The amount of fly ash was varied from 0% to 60% by mass of the binder material. Workability of SCC was characterized by the slump flow and the V-funnel tests. Test results showed that the workability of fresh SCC is improved by increasing the amount of fly ash. Compressive strength, splitting tensile strength and flexural strength decrease with the increase of fly ash. Fly ash can obviously reduce the drying shrinkage of SCC.*

**Keywords:** self-compacting concrete, mechanical properties, drying shrinkage.

## 1. Introduction

Self-compacting concrete, also known as self-consolidating concrete, is the most advanced trend in the field of concrete. SCC is a highly flowable concrete that can fill every corner of formwork under its own weight without the need of vibration, and consolidate without any segregation. The three material attributes of SCC are flowability, passing ability and stability. SCC has good flow ability and can pass through gaps between reinforcements. SCC is an extension of traditional concrete technology and offers improved engineering properties. Since its invention in the late 1980's, SCC has developed rapidly because of its obvious advantages [1-4]. SCC offers many benefits confronted by the conventional concrete, including shorter construction time, lower labor costs, better working environment, eliminating the vibration and improving the quality of concrete [5-7]. SCC is an advanced concrete building material that is regarded as the most revolutionary development in the concrete industry in recent decades. SCC has been widely applied in high-rise buildings, bridges, tunnels, hydraulic structures and precast concrete construction. SCC plays an important role in infrastructure and the application of SCC has grown tremendously [8].

Fly ash is a byproduct of the coal combustion process at power generation facilities. As a cementitious material, fly ash has been used as a partial replacement in concrete. The use of concrete containing fly ash has been increasing due to the technical and economical advantages. Fly ash can improve the durability of concrete, prevent alkali aggregate reaction and reduce total material costs [9]. Cement industry is highly energy consumer and contributes with about 5% in the global carbon dioxide emissions. Carbon dioxide is the primary greenhouse gas which is responsible for climate change. As a partial replacement for cement, use of fly ash has an favorable influence on the environment. In this study, the effect of fly ash on workability, compressive strength, splitting tensile strength, flexural strength and drying shrinkage of SCC were investigated.

## 2. Experimental program

### 2.1 Materials and mix proportion

Ordinary Portland cement was used in the experimentals. Fly ash was used as a partial replacement of Portland cement. The specific surface area of cement and fly ash was 462 m<sup>2</sup>/kg and 565 m<sup>2</sup>/kg, respectively [10,11]. The main chemical composition of cement and fly ash is presented in Table 1.

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Table 1

Chemical composition of Portland cement and fly ash.

Chemical analysis (wt. %)	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	SO <sub>3</sub>	Na <sub>2</sub> O	Loss on ignition
Portland cement	19.5	4.4	6.22	65.9	1.5	1.09	0.30	1.09
Fly ash	56.5	20.1	8.2	9.7	1.98	0.35	0.48	2.69

Table 2

Mixture proportions of SCC.

Mixture	Proportions (% by mass of binder)		Cement (kg/m <sup>3</sup> )	Fly ash (kg/m <sup>3</sup> )	Water (kg/m <sup>3</sup> )	Coarse aggregate (kg/m <sup>3</sup> )	Fine aggregate (kg/m <sup>3</sup> )	SP (% by mass of binder)
	Cement	Fly ash						
SCC-0	100	0	586	0	211	759	812	0.72
SCC-20	80	20	457	115	206	759	812	0.72
SCC-40	60	40	334	222	200	759	812	0.72
SCC-60	40	60	217	325	195	759	812	0.72

The coarse aggregate was crushed stone with a maximum size of 20 mm and the fine aggregate was natural sand with a maximum size of 5 mm. The fineness modulus of sand was 2.28. The four mixtures were designed and the replacement rate of fly ash varied from 0% to 60% by mass of the binder, consisting of cement and fly ash. Polycarboxylic ether superplasticizer (SP) was used in all mixtures to obtain the required workability. A constant water-to-binder ratio was maintained at 0.36 for all mixtures. The details of the mixture proportions are given in Table 2.

## 2.2 Test methods

The slump flow and the V-funnel tests were used to evaluate the workability of fresh SCC mixtures. The slump flow test aims at determining the filling ability of SCC. Filling ability is the ability of SCC to flow into all spaces within the formwork under its own weight. The apparatus consist of Abrams cone and base plate. The internal upper/lower diameter of Abrams cone is 100/200 mm and has a height of 300 mm. The flow time of the V-funnel test is the period a defined volume of SCC needs to pass a narrow opening. About 12 liter of fresh SCC is needed to perform the V-funnel test.

Cubes (100 × 100 × 100 mm) were used to evaluate the compressive strength and splitting tensile strength, and beams (100 × 100 × 400 mm) were used to evaluate the flexural strength in accordance with Chinese Standard GB/T 50081-2002. The SCC specimens were cast and cured at a temperature of 20 °C and tested at ages of 7 and 28 days. Three specimens were tested at each age for each mixture. The compression and splitting tension tests were performed using a digital compression machine with a capacity of 3000 kN. The flexural strength test is used to estimate the load at which the SCC specimens may crack. SCC

beam is loaded at one-third span point. Span of the beam is three times its depth.

Beams (100 × 100 × 515 mm) were used to evaluate the drying shrinkage of SCC. Length change measurements were taken using a dial gauge mounted along the longitudinal axis of the SCC specimens. Drying shrinkage tests were conducted in accordance with Chinese Standard GB/T 50082-2009. The drying shrinkage rate is defined as:

$$\varepsilon = \frac{L_0 - L_t}{L_b} \quad (1)$$

$L_0$  - the initial length of specimens.

$L_t$  - the length of specimens at the age of time  $t$ .

$L_b$  - the gauge length of specimens.

## 3. Results and discussion

### 3.1 Workability of fresh SCC

The slump flow diameter and V-funnel time of fresh SCC are shown in Figures 1 and 2, respectively. Slump flow diameter represents the yield stress and V-funnel time indicates the plastic viscosity [12].

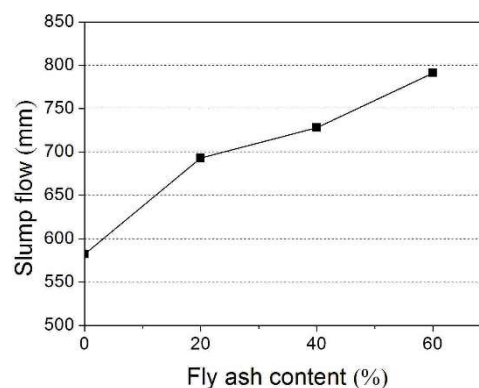


Fig. 1 - Effect of fly ash content on slump flow.

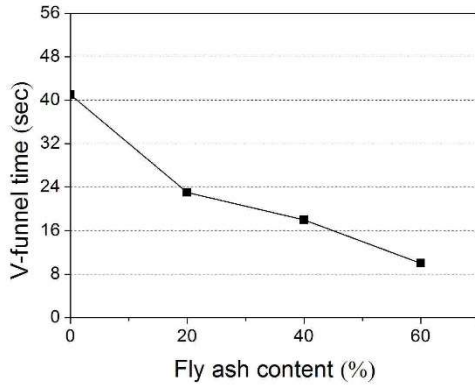


Fig. 2 - Effect of fly ash content on V-funnel time.

As can be seen in the Figure 1, slump flow values of all mixtures meet the design requirements. The maximum slump flow value is approximately 790 mm when the amount of fly ash is 60% by mass of the binder. The slump flow value can be increased by adding fly ash. In the Figure 2, the V-funnel flow of fresh SCC needs lesser time with the increase of fly ash content, indicating the decrease in plastic viscosity.

Workability of the mixtures containing fly ash was better than that of the mixture without fly ash. The use of fly ash reduces the water demand for a given workability. Therefore, SCC containing fly ash will have an increased workability at constant water-to-binder ratio.

### 3.2 Compressive strength

The results regarding the compressive strength test are showed in Figure 3. For 7 and 28 days compressive strength, SCC containing no fly ash achieved maximum strength. The addition of fly ash decreases compressive strength of SCC due to the dilution effect.

The maximum 7 days compressive strength is 35.0 MPa. In comparison with the mixture without fly ash, the amounts of 20%, 40% and 60% fly ash by mass of the binder cause the diminish of 7 days compressive strength with 11.5%, 26.7% and 53.6%, respectively. The maximum 28 days compressive strength is 48.3 MPa. Compared to mixture containing no fly ash, the addition of 20%, 40% and 60% fly ash by mass of the binder causes the decrease of 28 days compressive strength with 9.1%, 15.3% and 28.5%, respectively. The rate of decrease of compressive strength diminished with increasing curing time.

### 3.3 Splitting tensile strength

The results regarding the splitting tensile strength test are showed in Figures 4. All of the mixtures showed an increase in splitting tensile strength with increasing age of curing. The splitting tensile strength of mixture without fly ash is higher

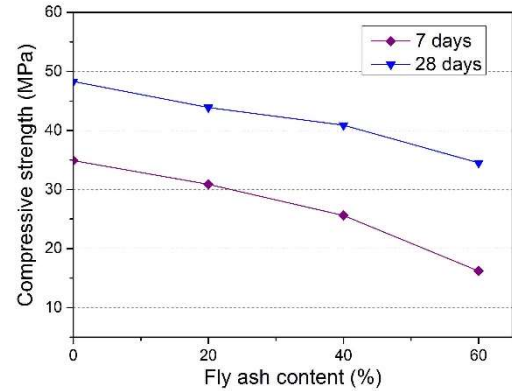


Fig. 3 - Effect of fly ash content on compressive strength.

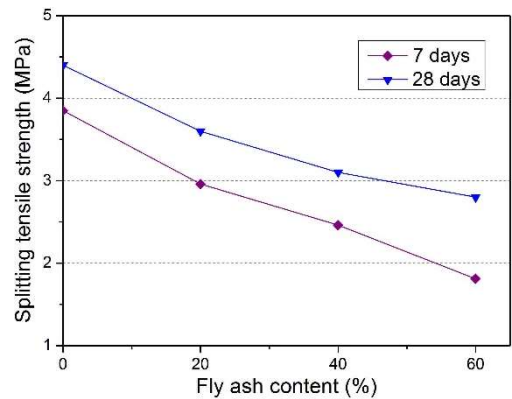


Fig. 4 - Effect of fly ash content on splitting tensile strength.

than that of mixtures containing fly ash. The splitting tensile strength decreases with the increase of fly ash content.

The lowest 28 days splitting tensile strength is approximately 2.8 MPa when 60% of the binder material is fly ash. Compared to mixture containing no fly ash, the addition of 20%, 40% and 60% fly ash by mass of the binder causes the decrease of 28 days splitting tensile strength with 18.2%, 29.5% and 36.4%, respectively. The amounts of 20%, 40% and 60% fly ash by mass of the binder cause the diminish of 7 days splitting tensile strength with 23.2%, 36.1% and 52.9%, respectively. The rate of decrease of splitting tensile strength diminished with increasing age of curing.

### 3.4 Flexural strength

The results regarding the flexural strength of the specimens with different fly ash content are shown in Figure 5. As can be seen in this Figure, the fly ash content influences the flexural strength and the increase of fly ash leads to a diminish of flexural strength, the more so as the fly ash content is greater.

The maximum 7 and 28 days flexural strength is 2.51 MPa and 3.10 MPa, respectively. In comparison with the mixture without fly ash, the amounts of 20%, 40% and 60% fly ash by mass of

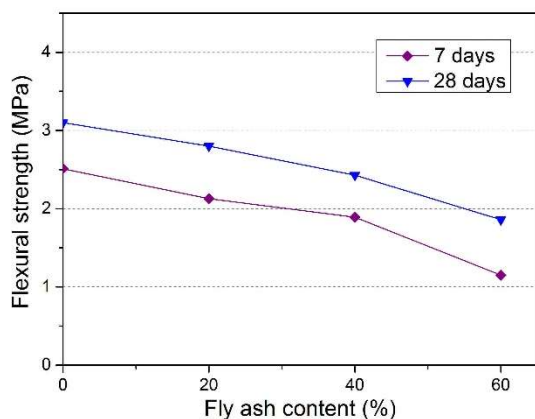


Fig. 5 - Effect of fly ash content on flexural strength.

the binder cause the diminish of 28 days flexural strength with 9.7%, 21.6% and 39.2%, respectively. The addition of 20%, 40% and 60% fly ash by mass of the binder causes the decrease of 7 days flexural strength with 15.1%, 24.7% and 54.3%, respectively.

### 3.5 Drying shrinkage

The results relating to the drying shrinkage of investigated SCC with fly ash content are shown in Figure 6. Drying shrinkage is considered as an important durability property and a major reason for the deterioration of concrete structures [13-15]. Cracking of concrete due to drying shrinkage results in higher repair costs and shorter service life of concrete structures. Drying shrinkage tests were conducted for a duration of 28 days. The addition of fly ash has a beneficial effect on the drying shrinkage of SCC. All mixtures indicates similar trend in the evolution of drying shrinkage. As can be seen in the Figure 6, fly ash addition determines decrease of the drying shrinkage of SCC specimens, but for all the compositions the drying shrinkage increases with the increase of the curing time. The higher the amount of replacement of cement by fly ash, the lower the drying shrinkage.

The value of the drying shrinkage measured at 7, 14 and 28 days for SCC containing no fly ash is  $2.10 \times 10^{-3}$ ,  $2.72 \times 10^{-3}$  and  $3.71 \times 10^{-3}$ , respectively. Compared to SCC containing no fly ash, the mixtures containing fly ash till 60% by mass of the binder show decreases of the drying shrinkage with 14.1%, 14.9%, and 16.2% for 7, 14 and 28 days of curing. In comparison with the mixture without fly ash, the amounts of 20%, 40% and 60% fly ash by mass of the binder cause the diminish of drying shrinkage at 28 days with 5.5%, 11.4% and 16.0%, respectively.

## 4. Conclusions

The use of fly ash was found to have a significant influence on workability, mechanical

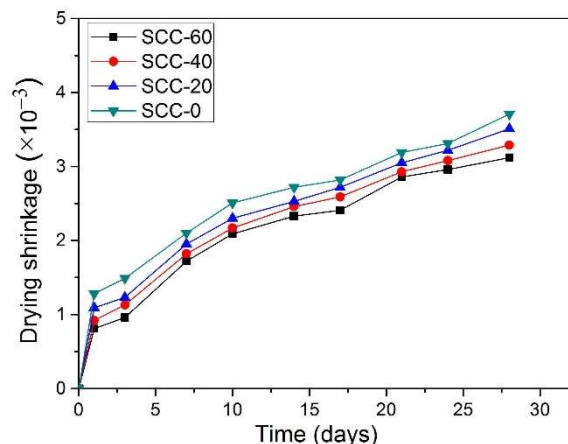


Fig. 6 - Effect of fly ash content on drying shrinkage.

properties and drying shrinkage of SCC. Based on the results obtained in this study, the following conclusions can be drawn:

The addition of fly ash can significantly improve the workability of SCC. The higher the percentage of fly ash, the higher the workability of SCC.

The compressive strength, splitting tensile strength and flexural strength diminish with the increase of fly ash content because of the dilution effect. SCC containing no fly ash gave the highest value of compressive strength, splitting tensile strength and flexural strength at 7 and 28 days of age.

Fly ash has a positive effect on the drying shrinkage and reduces the drying shrinkage of SCC. The drying shrinkage decreases with the increase of fly ash content at all ages of SCC.

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## MANIFESTĂRI ȘTIINȚIFICE / SCIENTIFIC EVENTS



### Borate & Phosphate 2017

St Anne's College, Oxford

24-28 July 2017

Organised by the Society  
of Glass Technology



The 9th International Conference on Borate Glasses, Crystals and Melts and the 2nd International Conference on Phosphate Materials will be held sequentially on 24-28 July, 2017, at [St Anne's College, Oxford](http://www.stanne.co.uk).

The Borate Conference is a forum for the discussion of current scientific research on borate materials (with a chemical composition that includes  $B_2O_3$ ,  $B_2S_3$  or  $B_2Se_3$ ). The Borate Conference will be held on 24-26 July 2017.

The Phosphate Conference is a forum for the discussion of current scientific research on phosphate materials (research on phosphate- and phosphate-containing materials, including P-O, P-S, P-Se and P-O-N networks). The Phosphate Conference will be held on 26-28 July 2017.

#### Conference Themes

- **Energy** including nuclear waste storage and electrolytes, super ionic systems and ionic conductivity.
- **Healthcare** including bone repair, bioactivity, dental and medical applications, glass ceramics and crystallisation.
- **Optical and data storage materials** including optical properties, glass fibres, luminescence, laser hosts.
- **Property-structure relationships** including mixed network glasses, structural modelling and simulations, mechanical properties, thermal properties, glasses in extreme conditions, glass ceramics, phase separation and inhomogeneities, thermodynamics, corrosion.
- **Fundamentals of the glassy state** including glass structure, short and intermediate range order, the glass transition, the boson peak, glass relaxation, crystallisation.
- **Novel glasses, crystals and melts** including synthesis and characterisation.
- **Technology and Industry** including current applications and future developments.

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