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MODULUS OF ELASTICITY OF SELF COMPACTING CONCRETE WITH DIFERENTS LEVELS OF LIMESTONE POWDER

BY

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Abstract. Self compacting concrete (SCC) is a relatively new material in building industry, which doesn’t require mechanical compaction. The material’s high fluidity allows the flow under its own weigh through the narrow sections, around the reinforcement, filling completely the formwork without segregation. The capacity to spread of SCC is attained by increased powder content and limited coarse aggregates volume. The most commonly mineral addition is filler limestone, an industrial by product. The properties of fresh SCC were thoroughly studied, but the investigations of the characteristics of hardened SCC remains inconsistent. The changes made to the concrete composition modifies mechanicals characteristics. In this study is investigated the influence of limestone powder content on the compressive strength and modulus of elasticity.

Keywords: self compacting concrete; limestone powder; compressive strength; modulus of elasticity.

1. Introduction

Self-compacting concrete (SCC) represents one of the most significant innovations in the concrete technology of the last years. This material is

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characterised by a high fluidity and stability, which is able to flow under its own weight, without any mechanical compaction and filling perfectly the formwork. The viscosity of SCC allows the spread around the reinforcement, through the narrow sections, without manifesting segregation or bleeding. (Parra *et al.*, 2011).

The properties of fresh mixtures and their test methods were thoroughly studied since its discovery. The advantages provided by fresh SCC are: enhanced construction productivity and construction rate, improved work environment (elimination of vibration), attaining sustainable characteristics, increased overall quality of the cast structures and reduced overall cost of the structure (Almeida Fihlo *et al.*, 2010).

To achieve this behaviour using similar components as in conventional concretes (CC), is necessary to change the components dosage. SCC contents larger amount of fines (cement and mineral admixtures), limited volume of coarse aggregate, restricted allowable particle size and powerful superplasticizers. Alternatively, when limited quantity of powder is used, the required mixture viscosity is obtained by introducing the viscosity-modifying admixtures (VMA). These mainly consist of high molecular weight, water soluble organic polymers, capable of absorbing and assigning part of the free water content and stabilise the consistency and rheological properties of SCC. (Łazniewska-Piekarczyk, 2013). Supplement of mineral admixtures such as limestone filler, fly ash or slag (used to enlarge the paste content) represents the most commonly SCC production method due to the improved stability of mixes and its low fabrication costs.

Limestone powder is a mineral admixture, widely available by-product, which has been added in cement and concrete production for many years, especially in Europe. It is chemically inert and has a limited influence in the hydration process. (De Schutter, 2011) The calcite $CaCO_3$ (main component) reacts with various calcium aluminate hydrates to form high and low forms of carboaluminates. Also contributes to the formation of ettringite, which increases the hydrated phase and decreases the overall porosity. (Celik *et al.*,2015)

This composition adjustment may have an influence on the SCC mechanical properties, which were conventionally approved analogous to conventionally concrete. One of the most significant mechanical parameters of concrete is the elastic modulus, which indicates the concrete ability to deform elastically (Khayat *et al.*, 2014). Its value represent is used in determining the prestress loss in pre-tensioned concrete elements. In addition, the knowledge of the modulus of high-strength concrete provides avoiding extreme deformation, stipulating adequate service ability and attaining the most cost-efficient designs.

The elastic modulus value of the concrete depends on the volume and type of the coarse aggregates. The passing ability of fresh SCC requires a higher paste volume than traditional vibrated concrete, which involves a reduced amount of aggregate content.

Due to the substantial contribution of coarse aggregates to the general stiffness of concrete, it is typically assumed that SCC is described by a lower modulus of elasticity. The European Guidelines for Self-Compacting Concrete specified that the value of this material can be slightly lower compared to conventional concrete, but the difference is covered by the safe assumptions provided in EN 1992-1-1 (Efnar *et al*., 2005). Domone specified a decrease of elastic modulus value up to 40% than CC mixes of low strength levels and up to 5% for high strengths concrete (Domone, 2009). In this study, were investigated the effects of different quantity of limestone filler on the compressive strength ant the elastic modulus value of SCC at 28 days on the cylinders specimens.

2. Experimental Procedure

2.1. Materials

All mixtures were prepared by using an Ordinary Portland Cement (42.5R), conformity with EN 197-1 standard and characterised by very high strength development. River washed aggregates included sand conforming to fractions 0,...,4 mm and two gravels fractions of 4,...,8 mm and 8,...,16 mm with a specific gravity 2.7 were used. As mineral admixture were employed local limestone filler with 2.6 specific gravity. The superplasticizer (high range water reducing) was of the polycarboxylate type, with a density of 1.04 kg/m^3.

2.2. Mixture Proportions

The concrete mixture proportions are shown in Table 1. The differences considered for mixture selection were: cement content, the aggregate gradation, the limestone quantity and w/c ratio. The cement content was fixed by two mixtures, the ratio between coarse and fine aggregates aggregate quantity was fixed at 52%: 48% for mixtures with odd number and 50%: 50% for mixtures with even number, proportion of limestone powder for the SCC1, SCC3, SCC5 higher than SCC2, SCC3, SCC6 as well as w/c ratio.

The workability of concrete according to European guideless for SCC: slump flow, V-funnel and passing ability was constant.

Table 1
Details of the Mix Proportions, [kg/m^3]

Material	Cement	Aggregate	Sand	Limestone filler	Limestone filler, [%]	W/C	HRWR
SCC1	320	881	814	160	33.1	0.53	4.5
SCC2	320	883	883	150	31.9	0.50	4.8
SCC3	340	876	809	150	30.6	0.53	5.1
SCC4	340	876	876	140	29.1	0.50	5.4
SCC5	360	876	809	130	26.5	0.53	5.1
SCC6	360	853	853	120	25.0	0.50	5.8

2.3. Mixing and Casting

Firstly, the coarse the small aggregates were mixed in a free-fall concrete mixer. Then cement and the limestone water were added and mixed until attained a uniform distribution, sequential, 70% of water was added into the mixer and continued to blend. Throughout that time, the mixer was stopped if required to remove fine particles from the mixer walls. At last, the superplasticizers with the remaining water was added and mixed to obtain a homogeneous mix.

The mixtures properties in fresh state were evaluated according to the procedures established by EFNARC standards, the workability was determined by slump flow test, V-funnel and L-box test. The results of testing are presented in Table 2. The fresh concrete was placed in a steel cylinder mould of 100 mm diameter and 200 mm height. After 24h of casting, they were demoulded and stored in water for 28 days.

Table 2
Workability Tests Results

Test	Slump flow		T_{500}, s		V-funnel, s		L-box	
	Value mm	Class	Value s	Class	Value s	Class	Value	Class
SCC1	680	SF2	4.2	VS2	14.4	VF2	0.84	PA2
SCC2	665	SF2	4.3	VS2	15.1	VF2	0.85	PA2
SCC3	690	SF2	4.1	VS2	11.3	VF2	0.88	PA2
SCC4	710	SF2	3.5	VS2	9.4	VF2	0.94	PA2
SCC5	720	SF2	2.9	VS2	9.2	VF2	0.93	PA2
SCC6	700	SF2	2.5	VS2	9.8	VF2	0.91	PA2

2.4. Test procedure

The experimental investigations were carried out the in laboratories of Faculty of Civil Engineering and Building Services from Iaşi. The modulus of elasticity was determined using a Humboldt compressometer, equipped with digital microcomparator and system of levers necessary to make corrections when recorded unsymmetrical strain (Fig. 2).

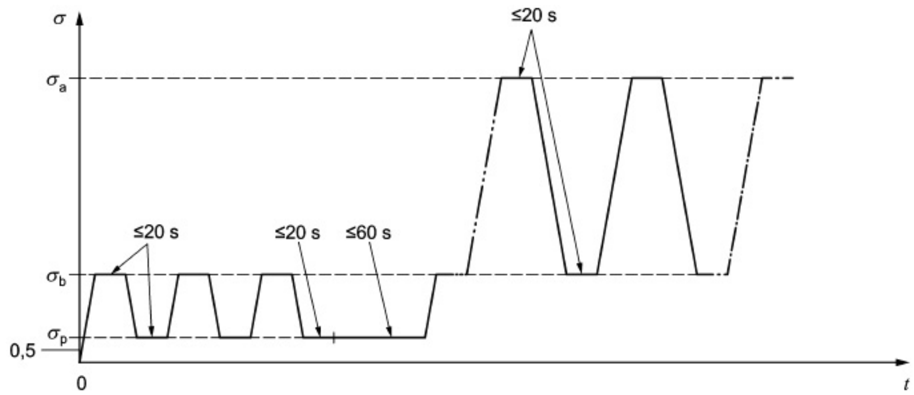

Fig. 1 – Determination of secant modulus of elasticity (EN 12390-13:2013 2013): ——— loading cycle; — · · · loading cycle for determination of initial secant modulus of elasticity; — · — loading cycle for determination of initial secant modulus of elasticity; σ – applied stress, [MPa]; σ_a – upper stress – $f_c/3$; σ_b – lower stress – $0,1 \cdot f_c/3 \leq \sigma_b \leq 0,15 \cdot f_c/3$; σ_p – preload stress $0,5$ MPa$\leq \sigma_p \leq \sigma_b$; t – time, [s].

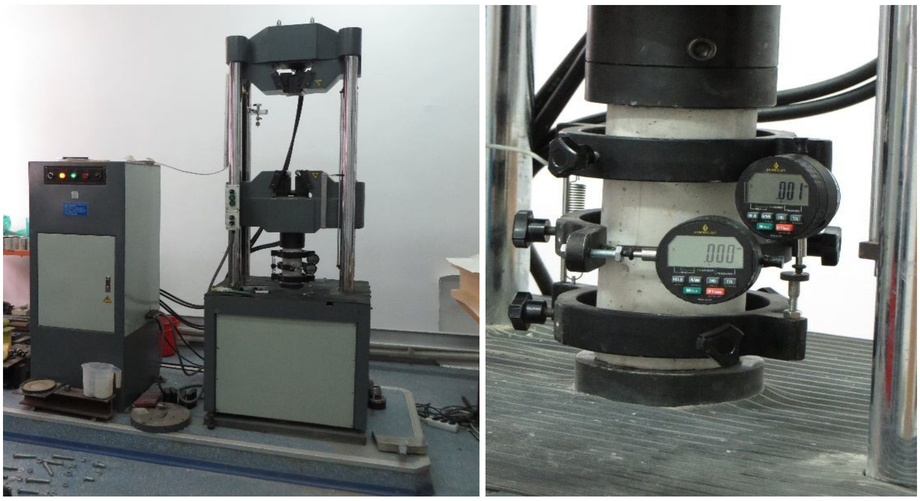

Fig. 2 – Experimental determination of modulus of elasticity.

Determination of secant modulus of elasticity was performed by determination of initial and stabilised secant modulus of elasticity according to

EN 12390-13:2013. The specimen was carried out to three preloading cycles to check wiring stability and positioning. The applied stress to the specimen was a rate of (0.6 ± 0.2) MPa/s up to the lower stress σ_b, and kept the nominal value for 20 s. Forwards, the stress was reduced at a rate of (0.6 ± 0.2) MPa/s down to the preload stress σ_p, and held for a period of 20 s. After the three cycles, the preload stress was maintained 60 s. Subsequent, three loading cycles were carried out. The stress was increased at a rate of (0.6 ± 0.2) MPa/s from the preload stress to the lower stress and maintained for 20 s. At the end of this period, the stress was reduced at σ_b and kept 20 s.

The test cycle for the determination of elastic modulus is given in Fig 2.

3. Results and Discussion.

3.1. Fresh Properties of SCC

The self compacting ability of fresh concrete was determined with slump flow test, V-funnel test and L-box test. The slump-flow value relates the mixture ability to spread in unconfined conditions and provides more information on the mix stability and uniformity. All the mixtures were catalogued as SF2 class.

The V-funnel time value indicates the rate of flow, which describes the viscosity of SCC, mixtures with a low viscosity have a very quick initial flow and then stop. This parameter is important where a good surface finish is demanded or reinforcement is very congested. The mixtures used in this study were VF2 class.

Passing ability represents the facility of the fresh mix to spread through limited spaces and narrow openings without segregation, loss of uniformity or producing blocking. The results of tested SCC properties in fresh state are showed in Table 2.

Table 2

SCC properties in fresh state

Test	Slump flow, mm	T_{500}, s	V-funnel, s	L-box
SCC1	680	4.2	14.4	0.84
SCC2	665	4.3	15.1	0.85
SCC3	690	4.1	11.3	0.88
SCC4	710	3.5	9.4	0.94
SCC5	720	2.9	9.2	0.93
SCC6	700	2.5	9.8	0.91

3.2. Compressive Strength

The compressive strength expresses one of the most important mechanical characteristics of concrete used in design rules. Eurocode 2 the concrete is classified entirely on the basis of this parameter. The compressive strength represents the ratio of the specimen failure load and its cross sectional area. Concrete hardens and acquires strength as it hydrates.

$$f_{c,\text{cyl}} = F/A, \tag{1}$$

where: F is the failure load, [N]; A – specimen cross sectional area, [mm^2].

The addition of limestone powder contributes to the filling of the gaps among coarse particles, reducing the porosity and increasing the density of concrete. The denser microstructure of SCC and enhanced bonding to the aggregates lead to a more uniform stress distribution during compression, which decreases the chance of premature failure. The test results of hardened concrete are given in Table 3.

Table 3

Compressive Strength, MPa

	SCC1	SCC2	SCC3	SCC4	SCC5	SCC6
1	33.89	43.42	36.32	37.20	40.06	42.93
2	34.65	41.63	33.98	37.47	34.03	40.57
3	30.40	38.17	31.38	40.55	34.22	40.31
4	29.70	43.15	29.37	41.96	33.42	40.03
5	28.86	40.29	40.12	34.93	34.19	37.74
Mean value	31.50	41.33	34.23	38.42	35.18	40.32

3.3. Elastic Modulus of Concrete

The slope of the stress-strain curve surrounded by the proportional limit of the material described the modulus of elasticity of the concrete. The secant modulus represents inclination of the straight line traced from the origin of axes to the stress-strain curve at some percentage of the ultimate strength. This is the value normally used in structural design. The usual approach of measuring the modulus of elasticity value is to determine the tangent modulus as the slope of the tangent to the stress-strain curve at some percentage of the ultimate strength of the concrete, which is determined by compression tests (Fig.3).

The secant modulus is practically same to the tangent modulus acquired at some lower percentage of the ultimate strength. The elastic modulus of concrete is an essential mechanical parameter expressing the ability of the concrete material to deform elastically. The bulk of the concrete volume represents the aggregate, their type, amount and E value have significant influence to the value of concrete modulus of the elasticity. SCC contents a higher paste volume, which is characterised by a higher deformability, which decreases the stiffness of the concrete. Increasing the compressive strength of the concrete, the paste's stiffness gains similar values to that of the aggregates, and consequently the paste's deformability is no more such a determining factor.

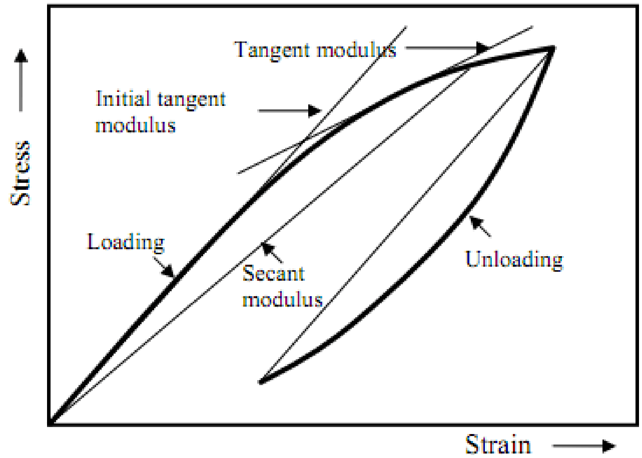

Fig. 3 – Elastic modulus of concrete (Neville, 2011).

According to the quantity of cement, the mixtures are grouped in three series, with different limestone powder content. The variation of limestone powder content between mixture of a series is around 1%, but the difference of E value constitutes 14.0%, 5.4% and 4.1% for the first, second and third series. The difference of the modulus of elasticity value amplified with the increasing of filler content about of 30% total powder materials. The mixtures of lower compressive strength showed a reduced value of Young modulus compared to EC2, the deviation reducing with the increase of compressive strengths. The results are showed in Fig. 4.

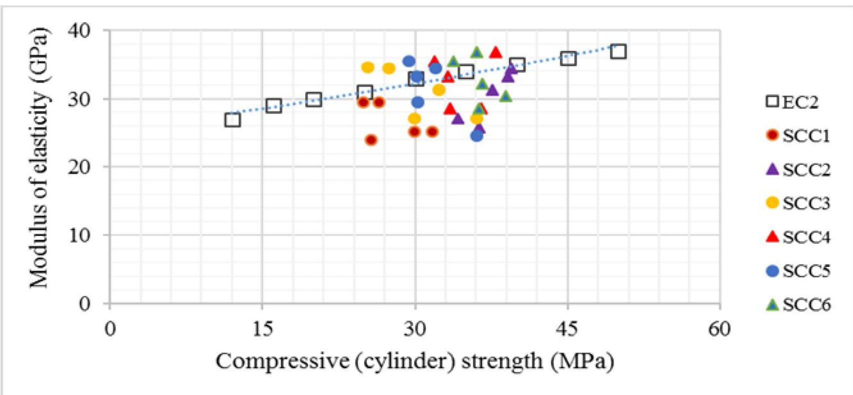

Fig. 4 – Modulus of elasticity *vs.* compressive strength of SCC.

4. Conclusions

Following conclusions can be formulate with respect to the influence of limestone filler on the SCC properties based on this database:

a) the addition of limestone powder improves the workability of SCC, increasing the fluidity and viscosity of the mixture;

b) the excess of limestone powder (more than 30%) increases the necessary for water and reduces the compressive strength;

c) the elastic modulus of SCC of lower strength are inferior comparable to the values indicated in EC2, the difference decreases at high strengths;

d) the addition of limestone powder about 30% of total powder content reduces significantly the modulus of elasticity value.

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MODULUL DE ELALASTICITATE A BETONULUI AUTOCOMPACTANT CU CONȚINUT VARIABIL DE FILER DE CALCAR

(Rezumat)

Betonul autocompactant (BAC) reprezintă u material relative nou în industria materialelor de construcție care nu necesită compactare mecanică la punerea în operă. Fluiditatea sporită a amestecului proaspăt permite acestuia să curgă sub influența greutății proprii, chiar și prin secțiunile înguste, armate intens, fără a produce segregarea. Abilitatea de curgere şi răspîndire a BAC este datorată conținutului sporit de parte fină şi a volumului limitat de aggregate grosiere. Cele mai întrebuințate adaose minerale reprezintă deşee industriale, printre care poate fi evidențiat filerul de calcar. Proprietățile BAC în stare prospătă au fost minuțios cercetate, studiile referitoare la caracteristicile acestuia în stare întărită rămân a fi inconsistente. În cadrul acestei lucrări sunt investigate efectele conținutului variabil de filer de calcar asupra rezistenței la compresiune şi a modulului de elasticitate.