INFLUENCE OF CALCINED CLAYS ON THE FRESH PROPERTIES OF SELF-COMPACTING CONCRETE

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Summary: *In this paper, the possibility of the use of calcined clay (CC) as a partial substitute for cement in self-compacting concrete (SCC) is investigated. The key characteristics of SCC are based on it's fresh properties; therefore, the investigation of these properties is the topic of this paper. As an ilustrative example of the described influences, a test of flowability and workability of the mix design containing 80% cement and 20% CC was conducted. The results of the preformed Slump-flow test show that the designed mixture satisfies the criteria set forth by the EN 206-9:2010.*

***Keywords**: Self-compacting concrete, calcined clay, slump-flow test*

1. INTRODUCTION

Self-compacting concrete (SCC) is defined as the concrete that is able to flow under its own weight and completely fill the framework without the need of any vibration, whilst maintaining homogenity (sustaining no segregation)[1]. The use of SCC instead of the regular concrete has many advantages, such as faster construction, reduced needed workforce, improved durability and reduced noise levels. Therefore, characteristics of SCC are being investigated worldwide and SCC will most likely soon become "regular concrete".

Concrete is probably the most widely used material on Earth, second only to water[2]. However, although it is very practical construction material, there are many serious problems regarding it's production, the main being CO_2 emission during cement manufacture (by 2025 the cement industry will be emitting CO_2 at a rate of 3.5 billion tons per year[3]) and enviromental damage through the extraction of raw materials (about 6 billion tons of concrete are produced every year, and every ton of cement,

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which makes 20-30% of concrete mass, requires approximately 1.5 tons of limestone[3]). In the past few decades, enviromental concerns regarding this problem caused considerable efforts to partialy substitute cement in concrete and mortar production by industrial wastes or by-products, other naturally growing materials or materials that require less energy to manufacture.

These suplementary cementitious materials (SCM) have to show puzzolanic reactivity to be able to bind agregate in concrete and so far a large variaty of them has been tested. The most commonly used are fly ash (usually used in dosage of 15-25% by mass of the total cementitious material), granulated blast furnace slag (usually used in dosage of 30-45% by mass of the total cementitious material), silica fume (usually used in dosage of 5-10% by mass of the total cementitious material), calcined shale and calcined clay (usually used in dosage of 10-20% by mass of the total cementitious material)[4], as well as various rock powders (marble, basalt, limestone, etc.).

In this paper, the state of the art of the use of calcined calys as partial cement substitute in SCC is reviewed, followed by a brief description of an experient undertaken by authors, as an example of this use.

2. INFLUENCE OF CALCINED CLAYS

The most available partial cement substitutes are clays. However, the chemical compounds of different clays vary greatly depending on with respect to their location. For clay to have a puzzolanic effect, it should consist largely of kaolinit, a clay mineral that is transformed to metakaolin (MK) through a thermal treatment and can then be used in production of high performance concrete, but most of the clays do not have this mineral in sufficient quantity.

From construction's point of view, it would be best to use kaolin (Chinese clay), i.e "pure clay", which consists almost solely of kaolinit and thus has the potential to provide concrete with great improvements in performance. More about it's use and influences will be said later. Here it is noted that, although it has many positive effects and is the most commonly used clay SCM, it is also an expensive one, due to the limited resources. Other, "impure clays", some of which are diatomite rock [3] and different types of shale, contain other clay minerals such as illite, montmorillonit, magnesium, quartz, etc.[5][6] to some extent. With their widespread availability and lower cost compared to pure kaolinite, these clays may become a competitive, more sustainable building material option. However, in spite of their availability, these non-kaolinite clay minerals are not used in concrete primarily due to their poor puzzolanic reactivity and a subsequent reduction in concrete mechanical performance [7].

In addressing this problem, many researchers are trying to improve the puzzolanic activity of these minerals. Thermal treatment in kiln at moderate temperatures, usually in range of 500^oC-1000^oC, a process called calcination, is the most common method in acheaving this. It collapses the crystalline structure of the mineral by evaporating the lattice hydroxyl groups, creating a highly reactive amorphous aluminosilicate that has high affinity for reaction with cement hydration products [7]. Non-kaolinit calcined clays (CC) have some, but often not strong enough puzzolanic effect. Therefore, additional ways of clay mineral activation are sought (the use of zincite, for example [7]), but so far none has given the satisfying results, leaving MK as the most suitable clay SCM. A review of the influence of MK on fresh properties of concrete follows.

Influence of MK on the fresh properties of SCC

As we've already said earlier, MK is the most commonly used partial PC replacement in SCC production at the moment.

The fresh as well as the hardened properties of SCC can vary greatly due to the influence of MK. However, reference data regarding the precise percentage of MK usage differ and very few authors are willing to vouch for it. The reason for this lies in the fact that the same amount of MK causes notably different results with different water to binder (W/B) ratios. The key to the solution lies in more experiments of the fresh properties of concrete.
The tests preformed on such a concrete in its fresh state would show the optimal level of MK replacement in SCC that would also satisfy the workability and required rheological properties. The most important workability tests are: *Slump flow*; T_{500}; *V funnel* and *L-box* test.
Slump flow and T_{500} are tests of mobility of the fresh concrete, and they have many similarities and differences also. Slump flow test is in fact the radius of the total fresh SCC casting, while T_{500} determines the time needed for SCC to spread to the diameter of 500 mm. V funnel test is specialized for determining the viscosity of the fresh mixture, while L-box test is used to estimate the casting and affinity of concrete for getting stuck between the rebars of the reinforcement.

The reference values that should be expected during the testing are given in Table 1.

Slump flow, viscosity and passing ability classes with respect to EFNARC [1].

Class	Slump flow (mm)	
Slump flow classes		
SF1	550–650	
SF2	660–750	
SF3	760–850	
Class	T_{50} (s)	V-funnel time (s)
Viscosity classes		
VS1/VF1	⩽2	⩽8
VS2/VF2	>2	9–25
Passing ability classes		
PA1	⩾0.8 with two rebar	
PA2	⩾0.8 with three rebar	

Table 1. Slump flow, viscosity and passing ability classes

The majority of researchers investigated the SCC using these tests, with MK involvement to a maximum of 25%. They have all come to a similar conclusion. In fact, with W/B factor ranging from 0.35 to 0.4, the optimum MK participation in PC is between 10% and 15%. Greater MK content causes the gradual "increase in density" of the fresh concrete and it's poorer workability, which can be demonstrated through the tests mentioned.

As a general example, the results achieved by R. Madandoust and S.Y. Mousavi [9] follow. They have tested three series of five samples using the described methods. Samples had been made with the MK content of 0; 5; 10; 15; 20%. The series have differed from oneanother in W/B factor, which was/has been 0.32; 0.38; 0.45%, respectively. The results are shown in the Table 2 [9].

Fresh concrete test results.

Mix group	Mix. ID.	Slump flow (mm)	T_{50} (sec)	V-funnel (sec)	Blocking ratio
G1	SCCL	680	2.48	6.1	0.84
	SCCL5	660	4.64	11.5	0.80
	SCCL10	700	6.16	19.6	0.81
	SCCL15	705	7.60	35.1	0.73
	SCCL20	675	7.97	37.1	0.67
G2	SCCM	670	1.90	5.2	0.91
	SCCM5	680	2.88	8.4	0.88
	SCCM10	675	4.32	14.8	0.80
	SCCM15	690	4.88	16.3	0.85
	SCCM20	670	6.56	27.1	0.75
G3	SCCH	690	1.30	5.0	0.92
	SCCH5	675	1.92	6.1	0.82
	SCCH10	715	2.56	9.1	0.85
	SCCH15	705	3.92	11.2	0.83
	SCCH20	685	4.08	12.9	0.76

Table 2. Fresh concrete test results

An overview on the fresh properties of SCC containing MK at different W/B ratios reveals that MK replacement up to 10%, generally satisfy the fresh-state behavior requirements related to high segregation resistance, deformability, passing and filling abilities. [9]
This experiment shows once again the proposed values for MK replacement of PC, although it is still recommended to check the fresh SCC mixtures for the, in that case, real influence of MK.

3. EXPERIMENT

During the fall of 2013 at the University of the German Federal Armed Forces, Munich, Germany, the influence of calcined clays on fresh properties of SCC was investigated.

The project was supported by Univ Prof Dr Ing K.-Ch. Thienel, and one of the authors of this paper took part in it.The calcined clay used, was calcined at the temperature of 750 °C, which contained several clay minerals (kaolinit, illit, montmorillonit, etc.). The Particle size was between 0.000 and 0.030 mm. The cement used in mixture was CEM I 42.5 R with high clinker content, produced by HeidelbergCement plant in Burglengenfeld. Mixture included the additive Sika ViskoFlow 20 (polycarboxylate organic additive) and river agregate/sand.

Table 3. Results of fresh SCC prepared with 20% calcined clay and 80% cement

Air temperature	20 °C
Water temperature	23 °C
Fresh concrete temperature	23 °C
Concrete spread	SF2(h1=700 and h2=720 mm)
Slump	VS 2, (5 s)
Air void content	5,2 %

The SCC mixture was made with calcined clay as a partial filler substitute and normal river agregate/sand. The density ranges between 2000 kg/m3 and 2800 kg/m3 classifying it as a concrete of normal density. The consistency class was determined in accordence to EN 206-9:2010.

<u>Fresh concrete tests:</u>

Using the same equipment as for the conventional concrete, the slump flow test was conducted. The concrete in the cone was neither compacted, nor shaked or vibrated in any way. After the lifting of the conus, the housed concrete collapsed and spreaded under it's own weight and the two perpendicular diameters of the casting were measured. The obtained results were 700 mm in one, and 720 mm in the other direction. According to EN 206-9:2010 this SCC classifies as SF2 (concretes of plastic consistency, with spread diameter within limits of 660 mm and 750 mm). Hence, the first condition was satisfied. Fresh concrete mass is show in Figure 1.

Figure 1. Concrete spread

A test method for evaluating the material segregation resistance of SCC, where the 500mm flow reach time is measured in the slump flow test above, that is, the time for the flow to reach 500 mm is measured in the slump flow test. SCC should give T_{500} = 2 - 5 seconds. [10]

Figure 2. Sucked air test

The amount of air sucked in the fresh concrete mixture was also tested (Figure 2), and the measured value was 5.2% (recommended values are 4-6%).

4. CONCLUSION

It has been demonstrated by many researchers that kaolinit in form of metakaolin can be used as an excellent cement substitute. However, it is still too expensive for a wider use, and therefore it's application is limited only to high performance concretes. If other clay minerals' puzzolanic reactivity was improved, the use of calcined clays would present a good choice in adressing the cement production reduction problem. At the moment, we have at our disposal no method for achiving this improvement, and are subsiquently directed to further investigate the potential of calcined clays activation and aplication and seek other means of replacing cement in concrete.

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УТИЦАЈ ПЕЧЕНЕ ГЛИНЕ НА СВОЈСТВА СВЕЖЕГ САМОУГРАЂУЈУЋЕГ БЕТОНА

Резиме: *У овом раду је приказана могућност примене печене глине (CC) као делимичне замене цемента у самоуграђујућем бетону (SCC). Како се кључне карактеристике самоуграђујућег бетона базирају на његовим својствима у свежем стању, управо је разматрање истих тема овог рада. Као провера и илустративан пример описаних утицаја, извршено је испитивање покретљивости и уградљивост мешавине која садржи 80% цемента и 20% CC-a. Добијени резултати на основу спроведеног Slump-flow теста показују да пројектована мешавина испуњава услове прописане EN 206-9:2010.*

Кључне речи: *Самоуграђујући бетон, печена глина, Slump-flow тест*