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EFFECT OF SUPERABSORBENT PARTICLE SIZE ON RHEOLOGY AND MECHANICAL PERFORMANCE OF CEMENT MORTARS

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The risk of crack propagation and autogenous shrinkage pose a significant weakness for concrete structures and substantially limits its lifespan. To overbridge related issues, the smart superabsorbent polymers (SAP) can be utilized to mitigate autogenous shrinkage and promote self-healing ability. However, incorporation of highly swelling particles struggles with the workability of the fresh mixture and thus final mechanical performance. Within this paper, the effect of SAP particle size is studied and correlated with the results of flow table test to propose an optimal relationship between the amount of SAP dosage, water/cement ratio and mechanical properties in the hardened state. The reference cement mortar mixture is modified by 0.25, 0.5 and 0.75 wt.% admixture of different 3 grades of SAPs thus the fresh mixture workability, basic material properties, compressive and flexural strength parameters are determined. The obtained results provide guidelines for the efficient design of SAP modified cement mortars mixtures with desired functional properties.

Keywords: Compressive strength, Porosity, Self-healing, Superabsorbent polymer, Granulometry.

1 INTRODUCTION

Portland cement-based binders are world widely the most used building material thanks to high durability and many other favorable properties. However, since the relationship between the material porosity, strength and amount of applied batch water was revealed, efforts to optimize concrete mixtures composition took place in order to decrease water dosage (Baloch *et al*. 2019). However, this trend, superior to improvement of mechanical characteristics, on the other hand, resulted in cracks occurrence. As was clearly reported, the autogenous shrinkage poses one of the major risks of concrete structures, especially in case of modern high-performance concrete mixtures (Zhutovsky and Kovler 2012).

Furthermore, this phenomenon can promote subsequent deterioration processes due to reinforcement exposure, water penetration, frost-thaw cycles or many others. The early formation of such cracks together with coupled effects of environmental and mechanical loading, cracks tend to spread rapidly. In other words, the substantial reduction of material serviceability and increased maintenance cost are correlated with this phenomenon (Vejmelkova *et al*. 2010).

To mitigate the concrete shrinkage, the utilization of several alternative materials as an internal curing agent were studied. In this sense, bentonite clay, rice husk ash or lightweight aggregates application have revealed the most favorable results considering the shrinkage control (Liu *et al.* 2019). Besides the materials listed above, incorporation of superabsorbent polymers

(SAPs) was found as a very effective tool for moderation of internal relative humidity and self-desiccation prevention. The internal curing capability of SAP particles is based on the continuous water release into the cementitious matrix in the case of relative humidity drops (Sun *et al*. 2019). The SAP internal curing is beneficial also from the point of hydration of unreacted cement particles. On the other hand, incorporation of SAPs to the cement binders struggle with the fresh mixture workability or compressive strength reduction (Ma *et al*. 2019). Since several types of SAPs having different particle size, chemical characteristics are swelling capability is available on the market, the design of such enhanced mixtures is accompanied with many issues which need to be investigated.

On this account, this study is focused on the determination of relationship between the particle size, SAP dosage and SAP applicability in cement-based mixtures design. The main aim of this paper lays in the elucidation of the influence of applied SAP admixtures on material properties of cement mortars in the hardened state. The influence of amount of applied SAPs dosage on the basic material properties is also revealed.

2 MATERIALS AND METHODS

2.1 Materials

Reference mixture of cement mortar composed by Portland cement CEM I 42.5 R, quartz sand 0-4 mm, superplasticizer (SP) Mapei Dynamon and water. Studied cement mortars within this study were modified by three types of superabsorbent polymers (SAPs) having a different particle size. Namely, Creasorb, Cabloc CT and Hydropam SAPs fabricated by Evonic (Germany) were utilized as internal curing agents. All materials, low-crosslinked sodium acrylate, are capable to absorb from 60 to 100 g of distilled water per 1 gram of the material. The performed particle size analysis carried out by Analysette 22 MicroTec Plus (Fritsch, Germany) exhibited following results: Creasorb d_{50} = 50 μm; Cabloc CT d_{50} = 200 μm; Hydropam d_{50} = 330 μm.

The cement pastes struggled with an increased water absorption capability of applied SAP particles, therefore water dosage needed to be adjusted to maintain the same workability level. The detailed composition of studied cement mortars is given in Table 1 (in kg/m^3).

Table 1. Composition of studied mixtures.

Mixture	Cement	Quartz sand	SP	Water	SAP type	SAP dosage (% by binder)
Ref	484	1722	5.3	160	-	-
CR0.25	481	1711	5.3	174	Creasorb	0.25
CR0.5	476	1693	5.3	197		0.50
CR0.75	469	1667	5.3	230		0.75
CA0.25	482	1715	5.3	169	Cabloc	0.25
CA0.5	479	1703	5.3	184		0.50
CA0.75	474	1686	5.3	207		0.75
H0.25	483	1717	5.3	167	Hydropam	0.25
H0.5	480	1707	5.3	179		0.50
H0.75	475	1690	5.3	201		0.75

2.2 Experimental Methods

Flow table test of cement mortars was determined on the basis of National Standard EN 12350-5. This test was carried out to investigate the effect of SAP on the rheologic properties and the need for additional water dosage.

The matrix density of studied cement pastes with SAP admixture was done by employing the helium pycnometer Pycnomatic ATC (Thermo Scientific). The bulk density results were delivered by common gravimetrical method by using digital caliper for the volume determination and laboratory weights. On the basis of the knowledge of the matrix and bulk density, the total open porosity was calculated. The basic physical properties were measured using 5 specimens of each material. The error of the measurement is 1.5% for matrix density and 3.6% for bulk density.

Compressive strength (MPa) and flexural strength (MPa) as the main mechanical parameters were determined by employment the device VEB WPM Leipzig having a stiff loading frame with the capacity of 3000 kN accordingly to the national standard ČSN EN 12390-3 (2007). The strength was determined after 28-days curing. The cubic samples were used for compressive strength test, while the prisms for flexural strength. All measurements were performed under laboratory conditions at a temperature of 22 ± 1 °C.

3 RESULTS AND DISCUSSION

First, the results of the basic material properties listed in Table 2 revealed a substantial effect of applied SAPs on material porosity. As one can see, a substantial increase in this parameter can be observed in line with upsurge of SAPs dosages for all studied mixtures. The relevance of this observation lays in a negative correlation between the strength characteristics and material porosity. However, this negative development, driven by increased water consumption within the mixing, differs for particular mixtures. The revealed decrease in the bulk density is noted especially for mixtures modified by SAP with a smaller particle size (Creasorb). This observation can be assigned to an improved swelling rate due to higher specific surface. The matrix density of all studied materials varied only minor and achieved changes belongs to the error of the measurement. Obtained slight drop can be assigned to a low density of SAPs (approx. 600 - 690 kg/m^3). Resulting open porosity of studied mortars varied from 12.3% (Ref) to 19.3% (CR0.75). Apparently, increased SAP dosages negatively affected the basic material characteristics for all mortar mixtures.

Table 2. Basic material properties of studied cement mortars.

Mixture	Matrix density (kg/m^3)	Bulk density (kg/m^3)	Open porosity (%)
Ref	2715	2380	12.3
CR0.25	2714	2329	14.2
CR0.5	2712	2265	16.5
CR0.75	2709	2187	19.3
CA0.25	2715	2338	13.9
CA0.5	2714	2281	16.0
CA0.75	2710	2213	18.3
H0.25	2714	2342	13.7
H0.5	2714	2288	15.7
H0.75	2711	2242	17.3

Looking at the mechanical performance of the composed cement mortars modified by Sap admixture, a clear trend corresponding with the development of basic material properties is visible. Evidently, the higher content of SAP substantially reduced mechanical resistivity compared to the reference mixture. The obtained decrease in the mechanical strength can be partially assigned also to increased water dosage described in Table. The pronounced drop of both compressive and flexural strength was obtained for mortars with Creasorb SAP. Here, about 27% diminution for compressive strength was achieved, respectively 28% for flexural strength in case of 0.75% SAP/binder dosage. The modification of cement mortar by other two SAPs did not result in such strength decrease. However, overall negative effect of applied SAPs on all studied mixtures was noted as a result of increased water dosage and resulting shift in the material porosity. Revealed strength drop comply with the results of Farzanian *et al.* (2016), who described the importance of w/c ratio on resulting strength of cement pastes modified by SAPs. On the other hand, the positive side-effect of SAP incorporation was pronounced by Hasholt and Jensen (2015) thanks to internal curing which occurs in SAP modified mixtures.

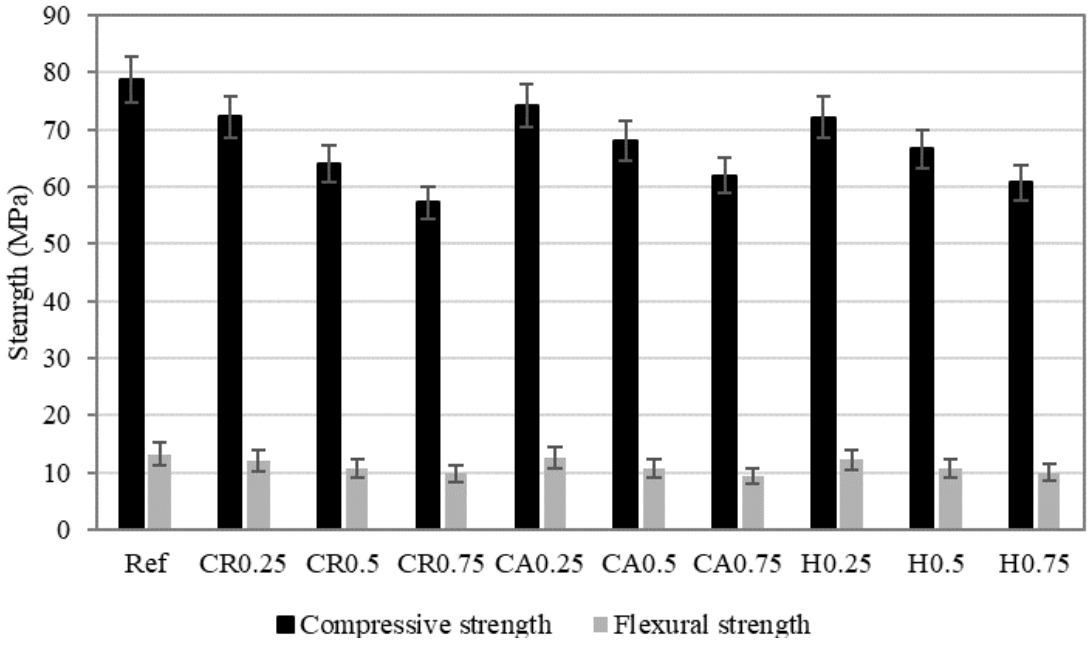

Figure 1. Mechanical parameters of modified mortars.

4 CONCLUSIONS

The present paper dealing with modification of cement mortars by superabsorbent polymers in order to distinguish the influence of such admixture on the basic material characteristics. In the light of the obtained results, an overall negative effect on all traced material properties was found. Namely, the drop in the compressive strength poses a substantial barrier for widespread application of SAPs despite the reported self-healing capability. As is evident, the precise selection of SAPs together with advanced mixture design is required in order to maintain satisfactory material properties and durability. The finer fraction of selected SAPs appeared as less suitable compared to SAPs having a mean diameter exceeding 200 μm. The obtained results need to be validated with strength parameters determined at later ages to identify the long-time effect of such admixtures where self-healing capability can be more beneficial. Besides the SAP

selection, the mixture design, particularly the w/c ratio need to be reduced as much as possible to preserve mechanical performance of such modified cement composites.

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