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Volume Changes of Cement Pastes Using Metakaolin

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Abstract: Shrinkage of concrete is an undesirable phenomenon accompanying maturation of concrete. These volume changes can be a source of cracks, which distorts the structure of concrete, and in its consequences leads to lower quality and durability of whole structures. To reduce the negative impact of shrinkage in addition to new knowledge about the properties of connective silicate-based systems and the positive effects of particulate fillers and fiber type used in various types of additives and ingredients. One of these additives is also metakaolin. In this paper we discuss the volume changes of cement mixtures with the addition of different amounts of metakaolin replacement for the cementitious binder, and its influence on the magnitude of volume changes in the process of hydration.

Keywords: Volume changes; Autogenous shrinkage; Microcracs; Metakaolin

1. Introduction - volume changes of fresh cement paste

One of the main factors influencing durability of concrete structures is the formation and development of cracks generated during hydration phase. This is particularly true for high strength concrete and massive concrete structures, but also for the concrete floors of industrial buildings, where this type of fault occurs very often. Since the early cracking is affected by various interrelated factors that influence the hydration process and the voltage stress, it is very complex behaviour, and no rational method of control has been created yet. The tension generated in concrete in the early stages, which causes cracking, is usually associated with three types of deformation [1]:

1. autogenous shrinkage caused by water absorption during hydration of cement particles (this contraction was the subject of this research),
2. shrinkage due to drying caused by evaporation of water during maturation of concrete,
3. contraction caused by temperature changes due to the lack of dissipation of heat generated as a result of cement hydration and cooling of the hot concrete.

Terminology in section of volume changes and definition of autogenous shrinkage is still under discussion due to ambiguous understanding of this process.

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The concept of chemical shrinkage can be found in the literature. This shrinkage indicates volume change, i.e. difference based on the total volume of input components (cement and water) and the final volume of hydration products, including growth of pores within the system. Autogenous shrinkage is defined as a reduction of the external sample volume, due to chemical shrinkage and it is kind of a subset of the chemical shrinkage [2]. In other literature, we can also meet with the concepts of internal and external autogenous shrinkage [3] or internal and external chemical shrinkage [4]. On the other hand, shrinkage due to drying is commonly considered the volume change caused by the evaporation of water from hardened concrete into the surrounding environment.

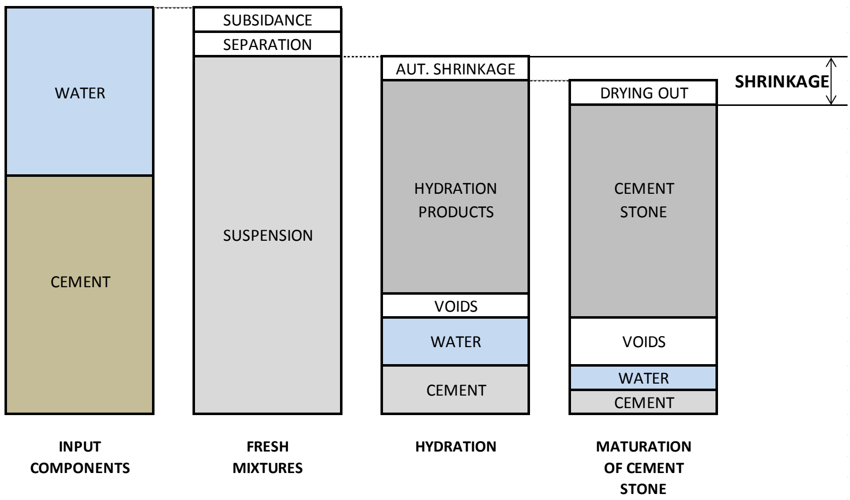

Fig. 1. Volume changes on cement pastes

2. The influence of metakaolin on volume changes

According to available sources, the partial replacement of cement by metakaolin influences the size of autogenous shrinkage. Whether there is a decrease or increase depends on many parameters, mainly on the amount of metakaolin in the mixture, and according to some sources, the water to cement ratio. Apart from this, other possible causes of volume changes for pastes of similar composition are presented. Such factors are the composition of cement and metakaolin, method and duration of treatment of samples, sample sizes and specific laboratory conditions [5]. The results presented in the literature are often contradictory, and it is difficult to deduce a conclusion on the effects of metakaolin in concrete from them.

Gleize et al. [5] did measurements of autogenous shrinkage of cement paste samples. In their work, measurement of shrinkage is evaluated, with 5, 10, 15 and 20% replacement of Portland cement with metakaolin, the water to cement ratio being w/c=0.3 and w/c = 0.5. In the early stages of hydration with a water to cement ratio of w/c=0.5, volume shrinkage values measured by them were lower than shrinkage of comparative samples without metakaolin. Cement paste with a water to cement ratio 0.3 showed higher values of autogenous shrinkage than comparative pastes.

In [7], it is quoted from the work of Wilde et al. [8], in which are the results of research of autogenous shrinkage of pastes with 5 to 25% replacement of cement with metakaolin, and the water to cement ratio being w/c=0.55. During the first 14 days of measurements all samples expanded, the only exceptions were the samples with 10% metakaolin. At the age of 14 to 45 days, in pastes containing up to 10% metakaolin, an increase in autogenous shrinkage was found, whereas in case of higher content of metakaolin the amount of autogenous shrinkage was reduced. For the pastes with 15% metakaolin the shrinkage was more comparable to the reference paste.

To somewhat different conclusions came Brooks and Megat Johari [6], who watched the autogenous shrinkage of concrete mixtures with aggregates with the grain size of up to 10 mm. They measured shrinkage from the beginning of hardening of the mixture to the age of 24 hours. They used 5, 10 and 15% replacement of cement with metakaolin, water to cement ratio was w/c=0.28. When compared to concrete without metakaolin, the shrinkage for all mixtures with metakaolin was lower at an early stage than that of comparative mixtures.

From the above it is clear that the effect of metakaolin on the size of autogenous shrinkage is dependent on many factors and will have a different effect in the cement paste and mixtures with aggregates. In addition, we come to quite different conclusions when comparing shrinkage at an early stage of cement pastes and the long-term shrinkage of concrete [5] [6].

3. Measuring of volume changes

Volume changes in concrete are mostly investigated by dilatometric gauges applied to already solidificated testing samples. It means that the volume changes produced in the process of solidification would not be detected. In this stage, a crystallic microstructure is created and the first microcracks emerge, thus affecting the final state of concrete elements and structures.

The proposed method (fig. 2) of using rubber wavy-line false mould gauges the linear variation by monitoring length changes of a coupled cement paste-rubber mould system. The test equipment comprised a holder preventing from a rubber mould misalignment in the horizontal direction and a movement laser sensor supporting the structure. The vertical deformation of test specimen is measured using a contactless distance measurement by optical method which allows continuous length measurement. Specimen size is: height 160 mm and diameter 70 mm.

Fig. 2. Proposed method of measuring of volume changes

4. Materials - composition of cement pastes

Cracks formation in the concrete at an early stage of hardening depends on the ratio of constituents, water to cement ratio and the conditions, under which hardening takes place. For new types of high-performance, high-strength and self-compacting concrete, hardening process is to some extent influenced by ingredients. Developing the production and application of cementitious composites is inherently linked to the progress of materials research. This paper is dedicated to volume changes of cement pastes with the addition of different amounts of metakaolin replacement for the cementitious binder, and its influence on the magnitude of volume changes in the hydration phase. Table 1 shows a composition of cement pastes. In all cases, Portland cement CEM I 42.5 R from locations Mokra and metakaolin Mefisto L05 were used. Water to cement ratio was w/c=0.3, except from mixture no. 6.

Table 1. Composition of cement pastes

Mixture	1	2	3	4	5	6
CEM I 42,5R	100%	95%	90%	85%	80%	75%
Metakaolin L0,5	0%	5%	10%	15%	20%	25%
Water cement ratio	0,3	0,3	0,3	0,3	0,3	0,32

5. Course of measuring and results

From each mix listed in the Table 1 two samples were prepared simultaneously. The mixture was poured into moulds in the shape of the bellows with a height of 160 mm and 70 mm in diameter. Length of the measurements was in all cases three days, the shrinkage was registered from the age of 20 minutes of the samples after mixing the mixture with water. Evaluation of the measured curves was relative to the beginning of the hydration process. From this point all measured curves are compared.

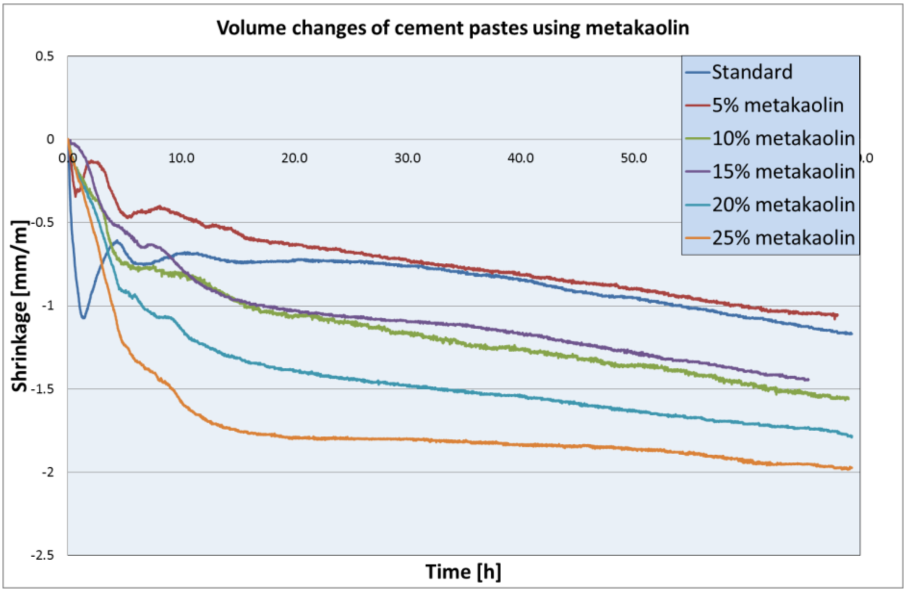

Fig. 3. Volume changes of cement pastes using metakaolin

Figure 3 shows the effect of representation of metakaolin in cement pastes. 5% replacement of cement with metakaolin has almost no influence on the size of the volume change, and after three days this shrinkage reached values of about 1 mm/m. The figure also shows that with increasing percentage representation of metakaolin in cement pastes grows the size of the shrinkage of the mixtures. Mixtures with 10 and 15% metakaolin showed a similar contraction after three days, which is in this case 1.5 mm/m. The biggest shrinkage values after three days were reached by the mixture with 25% share of metakaolin; it was almost 2 mm/m.

However, if we evaluate the size of volume changes after 10 hours from the beginning of hydration process, the results would have been different. Strength of mixture in this period reaches low values and is thus prone to cracking. In this case, the mixture with 5% share of metakaolin reaches smallest shrinkage values (0.5 mm/m). Reference mixture and mixtures with 10 and 15% share of metakaolin then reach similar values (around 0.7 to 0.8 mm/m). Other mixtures with higher proportions of metakaolin have already reached larger values of shrinkage in this period.

6. Conclusions

Autogenous shrinkage of cement pastes with 0-25% share of metakaolin was measured. The measurements clearly showed effect of metakaolin on the volume changes in the initial stages of hydration of cement. With the exception of the mixture with 5% share of metakaolin, it was found that partial replacement of cement with metakaolin leads to an increase in autogenous shrinkage. These results were obtained on pastes with water to cement ratio w/c=0.3 and with metakaolin

Mefisto L05. From the literature [5] [6], it is clear, that it would be appropriate to add these results with new measurements of mixtures with different water to cement ratios, possibly with other types of metakaolin, including various factions grinding. For practical use, it would be to measure autogenous shrinkage mixtures with aggregates.

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References

[1] Mihashi H., De B. Leite J.P.: Přehled stavu poznání o tvorbě trhlin v betonu v raných stádiích a možnostech jejího ovlivnění, *Beton*, 5, č.2, pp. 34-38, 2005

[2] Tazawa, Ei-Ichi: Autogenous shrinkage of Concrete, *Comitee report. In Proceedings of the international Workshop organized by JCI* (Japan Concrete Institut) – (Hiroshima June 13-14, 1998). London: E&FN Spon, p. 1-68, 1999

[3] Gagné, R., Aouad, I., Shen, J., Poulin, C.: Development of a new experimental technique for a study of the autogenous shrinkage of cement paste. *Material and structures*, vol. 32, p. 635-642, 1999

[4] Pumpr V.: Mechanismus rozpínání sulfoaliminátů v expanzních cementech. *Silikáty*, roč. 27, p. 175-188, 1983

[5] P. J. P. Gleize, M. Cyr A G.: Escadeillas, Effects of metakaolin on autogenous shrinkage of cement pastes, *Cement & Concrete Composites,* sv. 29, pp. 80-87, 2007.

[6] J. J. Brooks A M. A. Megat Johari: Effect of Metakaolin on Creep and Shrinkage of Concrete, *Cement & Concrete Composites,* sv. 23, pp. 495-502, 2001.

[7] Sabir, B. B., Wild, S., Bai, J.: Metakaolin and calcinated clays as pozzolans for concrete: a review. *Cement & Concrete Composites.* Vol. 23, No. 6, pp. 441-454, 2001.

[8] Wild S., Khatib J., Roose I.J.: Chemical and autogenous shrinkage of Portland cement-metakaolin pastes. *Advanced Cement Research*. Vol. 10, No. 3,pp. 109-119, 1998.