1. Introduction

Cracking of concrete and particularly the formation of shrinkage cracking is one of the major concerns in the durability of concrete structures. Appropriate concrete technology can help to avoid cracking and to provide improved durability. Smaller permeability, better water tightness, higher freeze-thaw resistance and higher resistance against aggressive chemical attack can be resulted.

To avoid shrinkage cracking several possible solutions are available mainly concerning the mix design, such as:

- use of expanding cements, use of shrinkage compensating admixtures, mixing concretes with low cement-paste content, mixing concretes of reduced sand content, and with effective curing of concrete.

Volume changes (i.e. shrinkage) due to loss of water are possible both in the fresh concrete and in the hardened concrete [1, 2, 3]. In the fresh concrete, loss of water by evaporation causes plastic shrinkage and can lead to surface cracking. Withdrawal of water from concrete stored in unsaturated air causes drying shrinkage [4, 5, 6]. Autogenous shrinkage (volume changes due to chemical reactions during hydration) is also discussed in technical literature, however, for practical purposes these relatively small changes need not to be distinguished from drying shrinkage [7].

Factors affecting shrinkage are the followings:
- volume of the cement stone,
- stiffness of the aggregate,
- possible water absorbing capacity of the aggregate,
- relative humidity of the ambience,
- climatic conditions (temperature, wind speed, etc.),
- volume-to-surface ratio of the concrete structure.

Prolonged moist curing of concrete delays the initiation of shrinkage, but the effect of curing on the magnitude of shrinkage is small [6]. On the other hand, prolonged moist curing can help to avoid crack formation due to higher tensile strength of concrete developed.

Drying shrinkage of concrete stored at unsaturated air can not be avoided as the equilibrium water content in the capillary pores is balanced at a relatively low water content [8]. Zero shrinkage of concrete is possible only at ~94RH% of the ambient that is not a usual case in civil engineering.

2. Advanced shrinkage compensation

Compensation of the shrinkage phenomenon and elimination of the shrinkage cracking need the following principal considerations:

1) a concrete mix of reduced cement paste content,
2) expansive cements or admixtures,
3) effective curing of concrete.

Reduced cement paste content can be reached either by decreased cement content or low water-to-cement ratio (i.e. low water content). Water-to-cement ratio can be reduced by superplasticizer admixtures.

Expansive cements or admixtures are developed to increase the volume of concrete after setting and during early age hardening. When concrete is properly restrained e.g. by reinforcement, expansion will induce tension in the reinforcement and compression in the concrete.

Fig. 1. illustrates the typical strain characteristics of shrinkage compensated and reference concretes [9].
Curing of concrete generally covers actions taken on the surface of concrete to keep the water inside that is required for hydration. With surface tension reducing admixtures we can also keep the water inside the concrete but without any action taken on the surface. The capillary tension in the concrete is directly proportional to the stress in the pore solution induced by desiccation. Reducing the surface tension of the pore solution is the most important controlling factor for the shrinkage reduction as the stresses which act upon the walls of the pores can be reduced [10,11]. The shrinkage reducing admixtures (SRA) are organic, water-soluble, hygroscopic compounds. As a result of the reduction of surface tension the evaporation of water is blocked. Therefore, also an internal curing effect takes place accompanied by the shrinkage strain reducing action.

In present experimental studies the Mapecrete system by Mapei was studied. The combined admixture system provides the use of the following three components, satisfying the above considerations:

1) Dynamon SR3 – superplasticizer agent,
2) Expancrete – expansive agent,
3) Mapecure SRA – internal curing agent.

A targeted effective shrinkage compensation can be realized by this combined admixture system and of its components. Dynamon SR3 superplasticizer agent fluid is a water solution containing 30% of acrylic polymers (with no formaldehyde). The polymers can efficiently disperse the cement grains and they can facilitate a slow development of hydration products within the concrete. Expancrete chloride-free calcium oxide based expansive powder is responsible for the volume change compensation during shrinkage of portland cement mortar and concrete. Mapecure SRA is a propyleneglycol ether based additive fluid that works by reducing the surface stresses of the water present in the capillary pores [12].

### 3. Experimental studies

Laboratory tests were carried out at the Budapest University of Technology and Economics (BME), Department of Construction Materials and Engineering Geology. To complete the detailed shrinkage analyses (up to age of 90 days), tests were carried out both on fresh concrete and hardened concrete of four different concrete mixtures: a self compacting concrete (SCC) for exposed surfaces, a high strength concrete (HSC), a concrete of improved water tightness and a steel fibre reinforced concrete (FRC). Details of concrete mixes are given in Table 1. Fresh concrete tests covered consistency measurements (flow and slump tests for conventional concretes; J-ring tests and V-funnel tests for SCC) as well as consistency endurance studies. Tests on hardened concrete specimens covered compressive strength development studies (from the age of 1 day up to 90 days) and standard water penetration tests.

Table 1

<table>
<thead>
<tr>
<th>Tested concretes and their mixing properties</th>
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<tr>
<td>A vizsgált betonok és jellemzőik</td>
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<tr>
<td>type of concrete without Mapecrete with Mapecrete difference</td>
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<td>steel fibre reinforced concrete (FRC)</td>
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<td>concrete of improved water tightness (W)</td>
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<td>high strength concrete (HSC)</td>
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<td>self compacting concrete (SCC)</td>
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Table 2

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<th>90 days results on shrinkage compensation of tested concretes</th>
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<td>A vizsgált betonok 90 napos zsugorodása</td>
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<tr>
<td>type of concrete without Mapecrete with Mapecrete difference</td>
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4. Experimental results

The combined admixture system was found to have considerable influence on the decrease of concrete shrinkage for all the four concrete mixes tested (Table 2). Also, the presence of steel fibres was found to have an effect on shrinkage. Almost the total shrinkage compensation expanding action took place on the first and the second days. Our experiments demonstrated that the shrinkage compensation mechanism for any kind of concrete mix is the same in nature. However, the rate and magnitude of shrinkage is strongly depending on the actual mix.

In case of the steel fibre reinforced concrete mix, both the combined admixture system and the steel fibres are utilized against the drying shrinkage (Fig. 2). Therefore, the 90 days shrinkage of this mix was found to be the most favourable (0.08 ‰), however, the shrinkage compensation expanding mechanism itself was not so significant as in the case of the self compacting concrete mix (0.24 ‰ and 0.31 ‰ decrease, for FRC and SCC, respectively).

In case of the concrete mix of improved water tightness, the shrinkage compensating action was not considerable due to the reduced cement paste content of this mix, according to the design of water tight concretes. The 90 days shrinkage of this concrete mix was rather limited either without the combined admixture system. However, the shrinkage compensation is still remarkable (0.31 ‰ decrease, see Fig. 3).

In case of the high strength concrete (HSC) mix, the considerably high early age strength was found to reduce the shrinkage compensation expanding mechanism up to the fifth day that can be studied in Fig. 4. As a result, almost no initial expansion is realized and therefore the 90 days shrinkage of the high strength concrete mix was not found to be favourable (0.22 ‰), especially compared to that of the other mixes studied.

In case of the self compacting concrete (SCC) mix, the granulated limestone provides a self-curing action, with which the shrinkage compensation expanding mechanism can be maintained for a longer period of time (Fig. 5). As a result, the efficiency of the combined admixture system is improved (90 days shrinkage is dropped to 25% of the original shrinkage of SCC without the combined admixture system).

Present experimental studies also demonstrated that the studied combined admixture system does not have disadvantageous influences on the properties of fresh concrete. Consistency studies were carried out in terms of flow tests and slump tests (with additional V-funnel and J-ring tests for SCC). Consistency endurance was studied up to 90 minutes. Results indicated that the combined admixture
system is applicable for all the four concrete mixes studied; usually with a beneficial influence on consistency that is not expected originally (e.g. the same consistency is reached at a lower superplasticizer agent content in the mix). Consistency endurance is also slightly improved by the studied combined admixture system.

It was found experimentally that the early age-, the 28 days age- and the 90 days age compressive strengths are increased by the use of the studied combined admixture system. For concrete mixes with cement CEM II (mix HSC and mix FRC in present experimental tests), the increase in early age strength reaches 100% (see Fig. 6. and Fig. 7.). Note, that results indicated both in Fig. 6. and Fig. 7. are corresponding to concrete specimens without any moist curing and stored at laboratory conditions up to 90 days age. The difference in the compressive strength realized is decreasing in time, but it is still considerable at the age of 90 days.

For concrete mixes with cement CEM III (mix W and mix SCC in present experimental tests), the increase in early age strength was not found to be remarkable; however, considerable increase in the 90 days strength can be realized (Fig. 8. and Fig. 9.). These favourable influences are attributed to the combined action of shrinkage compensation and self curing by the studied admixture system.

The self-compacting concrete exhibited the most sensitive behaviour concerning curing, in spite of the internal curing action provided by the granulated limestone. The difference between the 90 days compressive strengths of water cured and not cured concretes was found to be the highest among the four concrete mixes tested (see Fig. 9.). Presumably the high content of fine particles in the SCC matrix is resulted in the observed significant tendency of desiccation.

Results demonstrated that strength level of standard moist cured concretes can not be reached by the simple use of the studied combined admixture system as a substitute for curing.

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Experiments also demonstrated that the studied combined admixture system was found to be inefficient in gaining the strength of the concretes tested under standard curing conditions.
moist curing condition: i.e. no difference in the compressive strengths of reference and Mapecrete concretes was realized at the age of 90 days.

Water tightness was tested according to EN 12390-8:2000 at the age of 28 days (moist cured specimens) and also with the same procedure on concrete specimens that were stored at laboratory conditions up to 28 days without any moist curing. Water tightness tests were carried out on concretes for which the water tightness is of high significance (mixes HSC and W). Considerable differences in behaviour are demonstrated in Fig. 10. The studied combined admixture system yields very much improved water tightness for concrete. The influence is remarkable especially in the case where the specimens were not water cured. Results demonstrated that the studied admixture system helps the evolution of capillary pores of low permeability by its combined shrinkage compensation and self curing effect. Results predict that use of the Mapecrete system can be beneficial in the construction of watertight concrete structures where curing is of great importance and sometimes it is difficult to carry out.

5. Conclusions

In present experimental studies the Mapecrete shrinkage compensating and self curing system by Mapei was studied.

Results on four different concrete mixes proved that the studied combined admixture system is efficient in decreasing the drying shrinkage. The shrinkage compensation action was found to be more effective if the concrete was more sensitive to shrinkage in its origin.

Results demonstrated that the compressive strength of concretes is improved by the studied combined admixture system; however, the strength level of standard moist cured concretes can not be reached by the simple use of the combined admixture system as a substitute for curing.

The consistency, consistency endurance and resistance against segregation of mixes were slightly improved due to the addition of fine particles to the matrix by the expansive agent; contrary to the higher water demand expected.

Results demonstrated that the combined admixture system can exert an important influence also on the water tightness beyond its primary shrinkage reducing effect. The decrease in water penetration is especially remarkable in the case of specimens which were not moist cured.

Results also indicate the need of further experimental studies.

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