G. Hüsken; H.J.H. Brouwers

On the Early Age Behavior of Earth-Moist Concrete

Introduction

Cement based materials are by far the most common used building materials all over the world due to their favorable material characteristics, easy and safe handling, and the general availability of the raw materials in many countries. Besides the use of cementitious materials for the production of concrete used for structural and load bearing applications, concrete is also used for the production of mass products like paving blocks, slabs, curbs, roof tiles and sewage pipes. These types of products are mainly produced by using zero-slump or also so-called Earth-Moist Concrete (EMC). The beneficial properties of this type of dry concrete are allowing for short processing time as the products can directly stripped from the mold after the concrete is cast and compacted. Also the application of this type of concrete for building of roads, pavements and dams is a common used practice. In the last case, the maximum aggregate size of the zero-slump concrete is bigger and the concrete is named Roller Compacted Concrete (RCC). Traditional EMC mixes are characterized by moderate powder contents, high amount of fine and medium sized sands as well moderate gravel contents combined with low water content. Usually, the water to powder ratio is considered to be lower than 0.4 for EMC.
Although EMC mixes are used on large scale for the mass production of the aforementioned products, the applied methods for designing mixes are strongly geared to procedures and standards for standard concrete. Nevertheless, the regulations that apply to these products allow innovations such as cement reduction, application of stone sludge waste, a higher and tailor-made aggregate content, etc. In particular, the reduction and substitution of expensive primary filler materials (cement) by secondary stone waste materials is of vital importance for the cost reduction. Some first positive results regarding cement reduction and the application of stone waste materials could be achieved on lab scale by using a novel mix design concept for EMC mixes. The results of the laboratory investigations and a detailed explanation of the mix design concept are reported by Hüsken and Brouwers /1/. Figure 1 demonstrates how an optimized and denser packing of the granular concrete ingredients is influencing the strength of the hardened concrete.

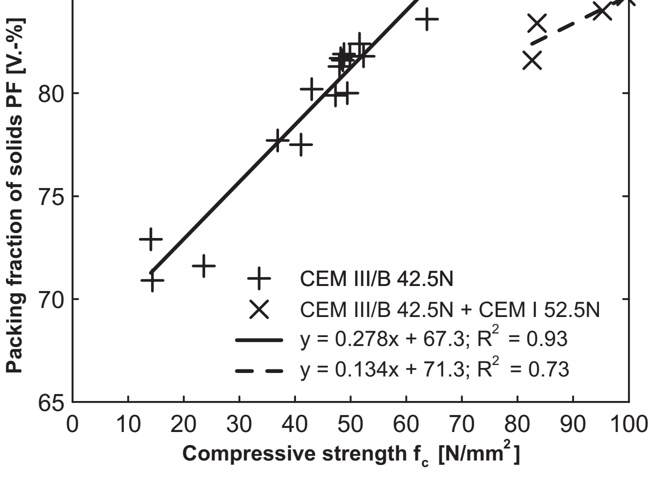

Fig. 1:

Influence of the packing fraction of solids on the compressive strength.

The particle packing can either be improved by higher compaction efforts, which implies usually the use of higher forces and is resulting in higher resistance of the applied machines and therefore cost intensive investments to strengthen these machines or the particles can be packed in a denser way by the right composition of the raw materials considering the granulometric properties of all ingredients, which can be done in a cost efficient way when the EMC mix is designed.

Not only the mechanical properties are influenced by an optimized particle packing but also the workability of the fresh concrete mix can be improved. In the past, relatively little attention was paid to the early-age behavior of EMC mixes as the poor workability causes problems when the concrete is handled under laboratory conditions. Sufficient and to the production process comparable degrees of compaction can hardly be achieved under laboratory conditions by using standard test methods for ordinary concrete as a high degree of compaction is necessary to achieve sufficient strength values immediately after demolding the fresh concrete products.

Capillary forces between the finer particles combined with the inner friction of the mix provide the required strength of the concrete in its early-age. This strength in the early-age is also called green-strength. In soil mechanics this phenomenon is referred to as apparent cohesion, which can only be activated in partially saturated fine sands or sandy soils. Here, the content of fines as well as the fineness of the smaller particles and the degree of saturation influences the capillary forces. The same principles are also determining the properties of EMC based concrete products directly after their compaction.

A thorough study on EMC with some investigations on the early-age behavior of EMC is presented by Bornemann /2/. Furthermore, work carried out by Juvas /3/ focus on the workability of EMC mixes using the intensive compaction test (IC-test). The results presented by Juvas /3/ show a promising and handy method for the test of EMC mixes under laboratory conditions.

Therefore, the ideas of the new mix design concept for EMC introduced by Hüsken and Brouwers /1/ will be combined with the evaluation of the designed mixes using the IC-test in order to relate the early-age behavior of EMC to the granulometric composition of the designed concrete mixes.

IC-test

The method and the equipment of the IC-test have been developed by I. Pakkinen /4/ in Finland in 1984 and where later adopted by the Nordtest method NT BUILD 427 in 1994 /5/. In general, the equipment of the IC-test can be used for testing the compactibility of granular materials like zero-slump concrete, soil, asphalt and other similar wet granular materials. The data of the IC-test give information about the workability of the fresh mix in regard to its compaction behavior. By means of the device, the optimum water content of a granular mix, e.g. concrete, can be adjusted for achieving maximum density.

The sample is compacted during the test by pressure and shear movement by a so-called shear-compaction principle (see Fig. 2). The pressure is introduced to the sample by compressing it between the top and bottom plate whereas the gyratory movement of the sample is resulting in shear forces. The applied pressure, rotation speed, as well as the inclination of the sample to the vertical axis of the device can be adjusted in order to vary the compaction efforts. For the test carried out on EMC mixes, the following working parameters have been applied:

- Cylinder inclination: 40 mrad
- Pressure in specimen: 250 kPa
- Working speed: 60 rpm

Furthermore, limiting values for the maximum compaction have to be given to the device. In the following, the criteria mentioned below have been used:

- Density limit: 2280 kg/m3
- Duration: 150 cycles

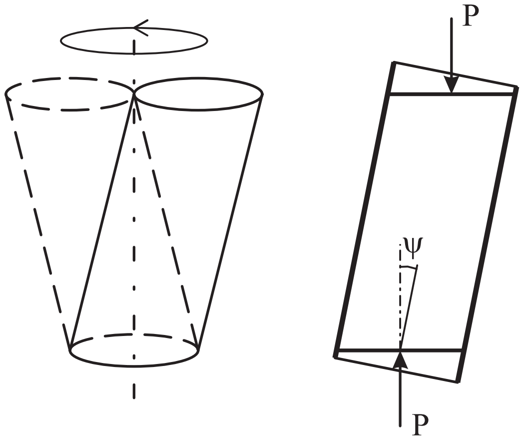

Fig. 2:

Working principle of the IC-test.

Fresh concrete tests

A common used concrete mix for the production of concrete paving blocks has been used for the first investigations on EMC mixes using the IC-test. Table 1 gives the mix proportioning of the tested EMC mix.

Material	Volume	Mass
	[dm^3]	[kg]
CEM I 52.5	83,2	262,0
Fly ash	50,8	114,2
Sand 1	304,0	805,5
Sand 2	218,2	578,1
Gravel 2-8	153,1	405,8
Water*	113,9	113,9
SP	0,5	0,5
Air	76,5	
Total	**1000,0**	**2280,0**

Tab. 1: EMC mix proportioning

* correspondes to water content of 5.3% based on the dry solids

Water content:

The water content of the granular mix is of vital importance for its compactibility and is influenced by the water demand of the fine material. A certain water layer around the particles is necessary which acts as a kind of lubricant and reduces the inner friction during the compaction process. The water layers around the particles form also air-water menisci at the contact points of the grains which are responsible for the interparticle forces. These forces are the cause for the green-strength or apparent cohesion of the EMC in its early-age. Furthermore, a minimum amount of water is required for the hydration process. Nevertheless, the theoretical required amount of water for a complete hydration is even exceeded by the low water to cement ratios applied in EMC. It is depicted in Fig. 3 and 4 how the water content is influencing the compaction behavior of the designed concrete mix.

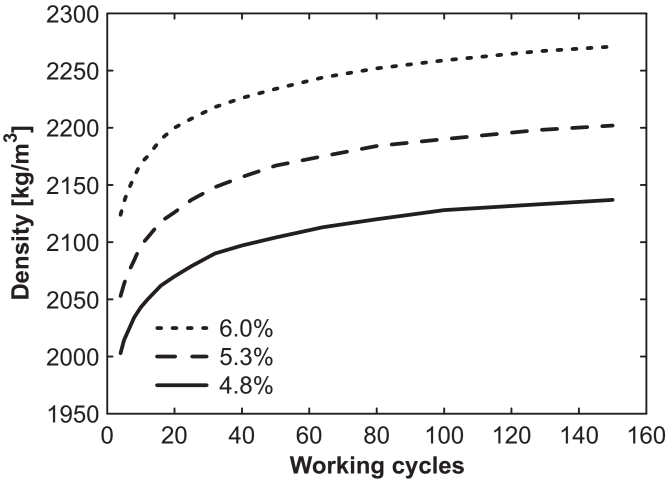

Fig. 3:

Influence of the water content on the workability (water content is based on M.-% of dry solids).

It is clear from both figures that an increase in the water content results in an increased final density. Furthermore, it is obvious from Fig. 3 that not only the final density can be increased by an higher water content but also the initial density is affected by changes of the water content. Although the water content was varied in a wide range, the slurry point of the mix was not reached. This point is characterized by an over-saturation of the granular material. As a consequence of this, water is coming out of the sample and the density cannot be increased further.

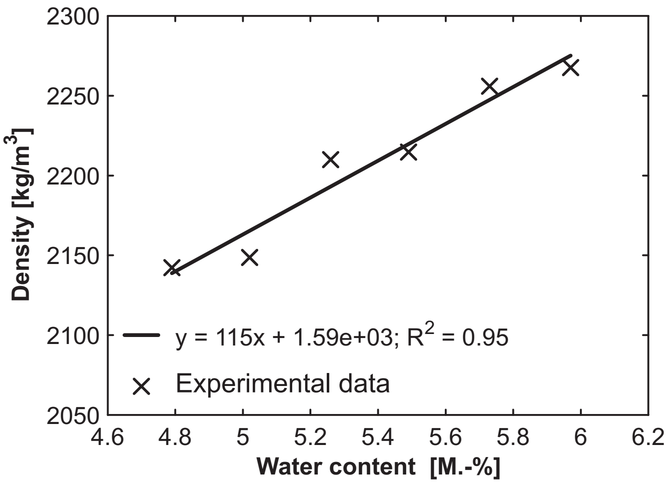

Fig. 4:

Influence of the water content on the density after 150 working cycles (water content is based on M.-% of dry solids).

Effect of chemical admixtures:

The use of organic chemical admixtures is common practice for other types of concrete like standard concrete or self-compacting concrete. Chemical admixtures help to reduce the water content of the concrete mix or can increase the workability and therewith the compaction behavior of the fresh concrete mix. Figure 5 shows the positive effect of a superplasticizer (SP) on the compaction behavior. A slight increase of the SP helps to increase the final density of the compacted sample while the water content is maintained. Unfortunately, the beneficial effect of the applied SP goes along with time dependency of the chemical admixture regarding its effectiveness. Figure 6 shows clearly that the positive effect of the SP is reduced over time.

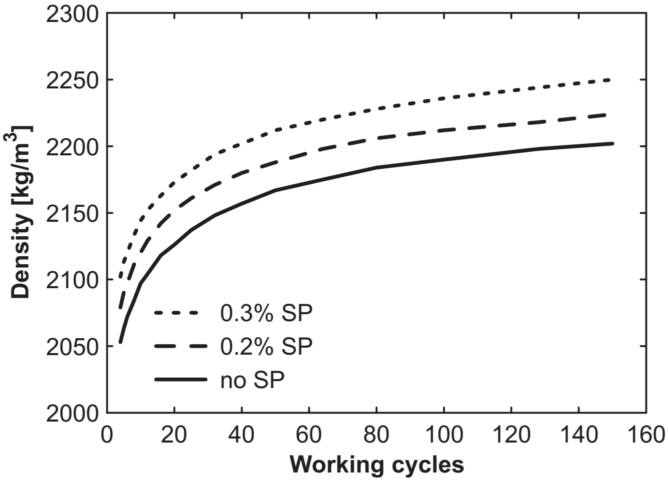

Fig. 5:

Influence of the SP content on the workability.

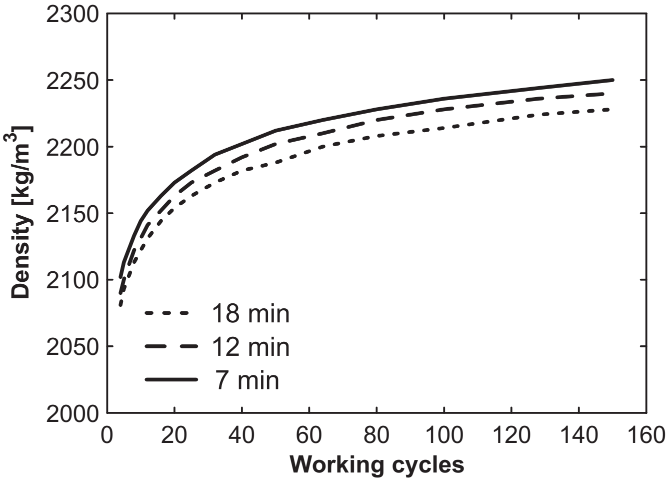

Fig. 6:

Time dependency of the SP effectiveness.

Conclusions

The preliminary tests showed that the IC-test is a suitable and useful test for the optimization of EMC mixes. Due to the automation of the entire test procedure, the test

is not depending on the operator as for example the Proctor test or the modified VB-test. One common disadvantage of these manual tests and their modifications is related to their manual way of compaction. Slight changes in the compaction process or even changes of the support of the test rig can influence the results. This is not the case for the IC-test uses standard and uniform compaction efforts which are calibrated.
The first results show that the IC-test can be used to adjust the water content as well as the amount of chemical admixtures to obtain a denser granular structure. Further research will focus on the optimum paste content of the designed EMC mix as well as the influence of the granulometric properties on the compaction behavior and the green-strength of the concrete.

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References

/1/ Hüsken, G. and Brouwers, H. (2008). A new mix design concept for earth-moist concrete: A theoretical and experimental study. Cement and Concrete Research 38(10): 1246–1259.
/2/ Bornemann, R. (2005). Untersuchung zur Modellierung des Frisch- und Festbetonverhaltens erdfeuchter Betone. Ph.D. Thesis, University of Kassel, Kassel, Germany (in German).
/3/ Juvas, K.J. (1996). Very dry Precasting concretes. In: Production Methods and Workability of Concrete, Proceedings of the International RILEM Conference, E & FN Spon, London, p. 125-140.
/4/ Pakkinen, I. (1986). Intensive compaction tester device for testing the compactability of no-slump concrete. Nordic Concrete Research Publication No. 5, Oslo, Norway, p 109-106.
/5/ NT BUILD 427 (1994). Compactibility with IC-tester. Nordtest method, Nordtest, Espoo, Finland.

Authors:

Dipl.-Ing. G. Hüsken
Department of Construction Management and Engineering (CME)
Faculty of Engineering Technology
University of Twente
P.O. Box 217

NL – 7500 AE Enschede

Dr. ir. H.J.H. Brouwers
Department of Construction Management and Engineering (CME)
Faculty of Engineering Technology
University of Twente
P.O. Box 217

NL – 7500 AE Enschede