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CONCRETE SHRINKAGE MECHANISM AND EXAMPLES OF CONCRETE WITH DIFFERENT RECYCLED AGGREGATES

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Abstract: Concrete shrinkage is reduction of its volume which is caused by hydration of cement and loss of moisture, independently of the external load. Aggregate can be considered inert in terms of volume changes, so concrete shrinkage is related only to cement paste shrinkage. Extent of shrinkage depends on the quantity and type of cement, water-cement factor, granulometric composition, type of the aggregate, strength of concrete, thermo-hygrometric conditions of the environment, wind velocity, etc. The paper presents two examples: the results of shrinkage of self-compacting concrete with recycled aggregate of crushed concrete and the results of shrinkage of vibrated concrete with recycled brick.

Key words*: concrete, shrinkage, self-compacting concrete, recycled concrete aggregate, recycled brick*

1. Introduction

Concrete shrinkage is reduction of its volume caused by hydration of cement and loss of moisture, independently of the external load. Bearing in mind that stone aggregate can be considered inert regarding volume changes over time, it can be concluded that concrete shrinkage is related to cement paste shrinkage. Cement paste shrinkage occurs because:

- volume of the hardened cement paste is less than the initial volume of the fresh cement paste – hydration shrinkage;
- evaporation of water in the cement bonding period – plastic shrinkage;
- evaporation of water during hardening of the cement paste in the period following the end of its bonding – hydraulic shrinkage.

Cement paste shrinkage is "transferred" to the concrete. But it should be borne in mind that concrete is inhomogeneous material, and therefore the extent of concrete shrinkage depends on the amount, type and properties of cement, water-cement ratio, granulometric composition and type of the aggregate, thermo-hygrometric conditions of the environment, wind speed, etc.

2. Plastic Shrinkage

Plastic shrinkage, as compared to other types of shrinkage (referred to in point1), is the largest. What is in this case good is the fact that it occurs in a time when the concrete slab is still to some extent fluid. However, due to non-homogeneous structure of concrete

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and the presence of reinforcement, plastic shrinkage is not uniform in the concrete slab, which leads to the formation of tensile stress, and further to the appearance of cracks. These cracks are usually formed on horizontal surfaces of concrete elements (especially in plates, Fig.1), then in places of connections with other elements, on contour elements and in similar positions, i.e. in places where rapid evaporation of moisture from concrete is possible. The appearance of cracks, due to plastic shrinkage, in practice is particularly expressed in conditions of high wind speed, low relative humidity, high temperature air, as well as high temperature concrete. It should also be added that these cracks, when formed, are often spread from one to the other edge of the element [1].

Fig. 2. Appearance of a crack on the surface of a concrete slab due to the plastic shrinkage

3. Hydraulic Shrinkage

It is known that concretes are made with greater amount of water than is necessary for hydration of cement, in order to achieve the desired consistency. After concrete hardening, the excess water evaporates, more slowly or more quickly, resulting in the so-called hydraulic shrinkage, which causes the appearance of stress in concrete. Restrained hydraulic shrinkage may cause cracking or distorting concrete elements. For these reasons, for example with plates, it is necessary to provide for expansion joints, in order to prevent the occurrence of random cracks and to possibly limit them at the desired location, where they can easily be fulfilled with adequate sealing material. In practice, hydraulic shrinkage is much more important than the previously described, plastic shrinkage. Factors affecting the extent of hydraulic shrinkage are numerous and can be related to the characteristics of cement paste, to the concrete itself, as well as to environmental condition.

When speaking of cement paste, the important factors are water-cement ratio, degree of hydration, type of cement, moisture content, presence of additives, and the temperature at which it hardens. Composition of cement affects the shrinkage of cement paste and concrete, but this impact is considered not to be great. The exact relationship between the composition of cement and shrinkage is not yet established. It is widely recognized that hydraulic shrinkage is greater if concrete is made of cement with additives, especially if they have higher fineness of grind. Higher dosages of cement contribute to greater shrinkage, especially in the case of dosages higher than 400kg/m^3 of concrete [2]. Concretes that are made with higher water-cement factors have greater hydraulic shrinkage, which is associated with their increased capillary porosity [3].

Volume change of concrete during drying, in the period of hardening, is not equal to the volume of water evaporated. Evaporation of the so-called free water, which occurs first, causes little or no shrinkage. With continued drying, adsorbed water also begins to evaporate, resulting in shrinkage of cement paste, i.e. of concrete. One of the important phenomena that needs to be taken into account, when considering hydraulic shrinkage, is the fact that part of the total shrinkage, that occurs during the first drying (which is the greatest), is irreversible [4].

Generally speaking, shrinkage (in total) is a process that initially takes place relatively fast in the course of time, but later, in a very long period of time, it decreases and by asymptote reaches a certain final value. Based on previous statements made in this point, it can be concluded that curing of fresh concrete using moistening (which is done by pouring water or in another appropriate manner) is very important to prevent early shrinkage. In this way, shrinkage cannot be avoided, but it can be postponed for a certain period of time. More precisely, it should be postponed until the moment when concrete reaches sufficient tensile strength and is able to receive tensile stresses caused by shrinkage, and to avoid the occurrence of cracks. It should also be said, that the postponement of the beginning of shrinkage almost does not affect the final value of shrinkage.

4. Experimental results

4.1. Concrete based on recycled brick

Concrete mixtures were made using ordinary Portland cement (CEM I 42.5R). Four types of concrete (A, B, G and H) had 350 kg/m^3 and two (D and J) 250 kg/m^3. Crushed bricks were separated into fractions 0/4, 4/8, 8/16 and 16/32 mm. Three kinds of concrete (A, B and D) were made using recycled bricks as aggregate. Other kinds of concrete (G, H and J) were made using combination of river sand and recycled bricks. Concrete mixtures B and H were made using polymer. It was latex BSR, with 47.4% of dry materials in dispersion. Information about composition of concrete is shown in Table 1. Concrete was placed by vibration on vibro – table [5].

Table 1. Quantities of component materials of vibrated concrete

Type of concrete		A	B	D	G	H	J
Cement (kg/m^3)		350	350	250	350	350	250
Aggregate (kg/m^3)	0/4mm	469	458	504	535	532	574
	4/8mm	161	157	173	184	182	197
	8/16mm	214	210	230	245	243	262
	16/32mm	496	485	533	566	562	607
Water (kg/m^3)	Apsorp.	224	219	240	165	164	177
	Free	79	51	40	85	61	33
Polymer (kg/m^3)		-	29.6	-	-	29.6	-

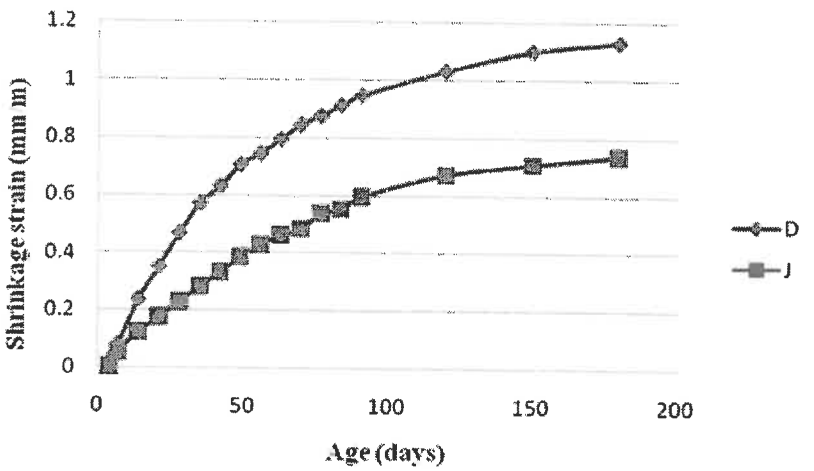

Fig. 2. Dependence on shrinkage strain versus time for concrete with cement content of 250 kg

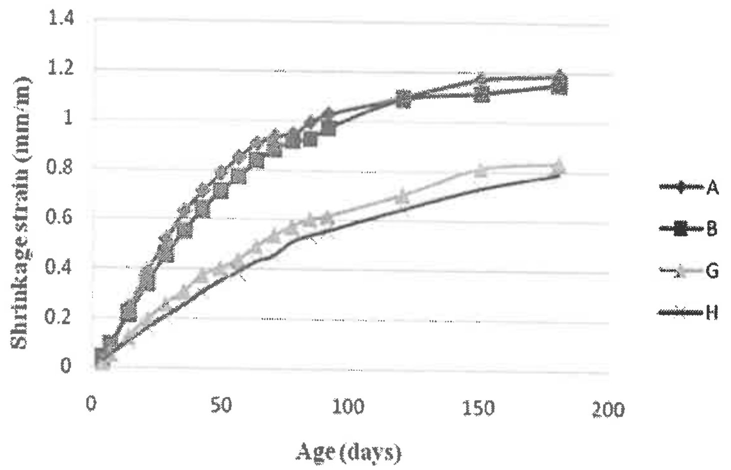

Fig. 3. Dependence on shrinkage strain versus time for concrete with cement content of 350 kg

Shrinkage of concrete was determined by testing prismatic specimens 12x12x36 cm age 4, 7, 14, 21, 28, ..., 91, 120, 150 and 180 days. The specimens were stored on temperature of 20°C and humidity of 65%. Obtained results are shown on Figures 2 and 3. With polymer shrinkage of concrete was decreased. This can be explained by greater effect of retaining the water in concrete. Polymer membranes cover the micro- cracks which may appear due to shrinkage preventing their enlargement.

4.2. Self – Compacting concrete with different mineral additives

For the purposes of the experimental work [6] nine three-fraction concrete mixtures have been made. Cement PC 42.5R (Holcim Popovac) has been used as well as mineral additives: lime (manufacturer "Jelen Do"), fly ash (from the power plant "Nikola Tesla B" in Obrenovac), and silica fume (product of Sikafume, a manufacturer of building chemicals SIKA); natural aggregate (Luka "Leget", Sremska Mitrovica), recycled aggregate obtained by crushing demolished retaining wall in the quarry Ostrovica, near Nis. Control concrete was made with each of the additives and a natural aggregate; in mixtures L50, F50 and S50, fraction 8/16mm was replaced by the recycled aggregate, and in mixtures L100, F100 and S100, both coarse fractions (4/8 and 8/16) were replaced by recycled fractions. In all the mixtures, superplasticizer ViscoCrete 5380 (manufacturer SIKA) has been used, which was dosed according to the manufacturer. The composition of the mixtures is shown in Table 2. The shrinkage results are shown in Figure 4.

Table 2. Quantities of component materials of Self – Compacting Concrete

	Cement (kg/m^3)	Lime (kg/m^3)	Fly ash (kg/m^3)	Silica fume (kg/m^3)	0/4mm (kg/m^3)	4/8mm (kg/m^3)	8/16mm (kg/m^3)	Water (kg/m^3)	VSC5380 (kg/m^3)
CL	400	120	0	0	770.86	306.28	532	170.8	4.94
CF	400	0	120	0	770.86	306.28	532	192.66	4.94
CS	400	0	0	52	770.86	306.28	532	185.71	4.94
L50	400	120	0	0	809.14	306.28	505.43	182.86	5.08
F50	400	0	120	0	809.14	306.28	505.43	214.28	5.08
S50	400	0	0	52	809.14	306.28	505.43	197.14	5.08
L100	400	120	0	0	809.14	306.28	505.43	189.5	5.08
F100	400	0	120	0	809.14	306.28	505.43	221	5.08
S100	400	0	0	52	809.14	306.28	505.43	208.6	5.08

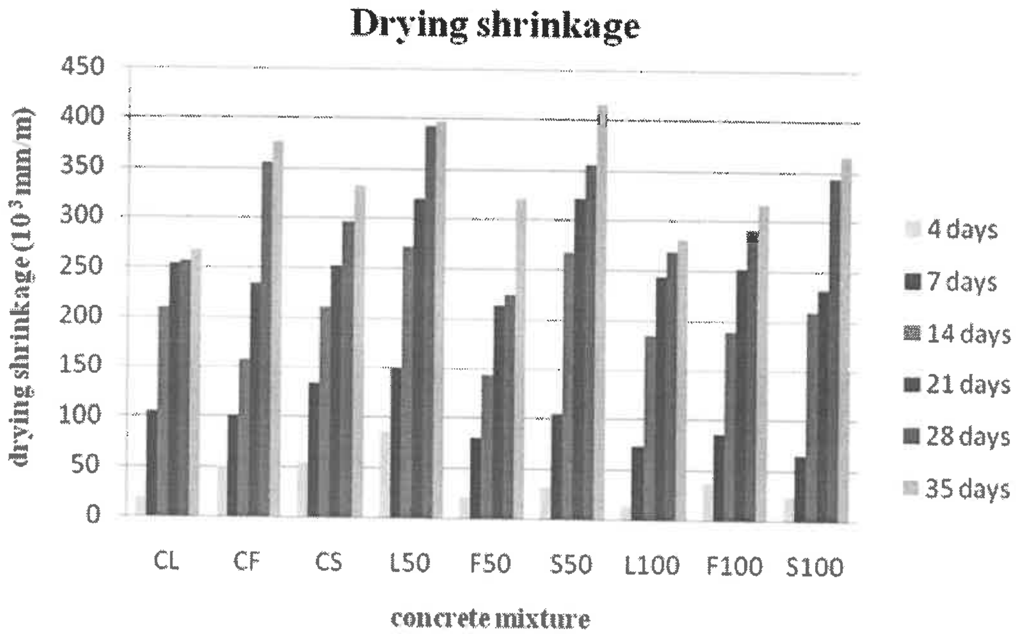

Fig.4. The shrinkage results for SCC with different mineral additions

The measurements done show that the largest shrinkage was found in the concrete mix with silica fume and III recycled fraction, S50, and the smallest in the control concrete with lime CL, wherein the difference is 56%. No regularities can be drawn from these results: mixes with III recycled fraction had greater shrinkage than mixes with II and III recycled fraction, wherein differences in lime and silica fume were more pronounced than in concrete with fly ash. If classification of concrete is done according to the mineral additive, the largest shrinkage was found in mixes with silica fume; if the criterion is aggregate, the largest shrinkage among control concrete mixes, was found in the control concrete with fly ash (29% more than in the control concrete with lime and 11.7% more than in the control concrete with silica fume); among mixes with III recycled fraction S50 (4.8% more than in mixes with lime and 22.8% more than in mixes with fly ash), and among mixes with II and III recycled fraction S100 (22.8% more than in mixes with lime and 13.2% more than in mixes with fly ash).

Conclusion

Shrinkage of cement paste and concrete depends on many parameters. Plastic shrinkage is, compared to other types of shrinkage, the largest, but what is rather suitable in practice, is the fact that it occurs at a time when the concrete slab is still to some extent fluid. Due to inhomogeneity of concrete structures and the presence of reinforcement, plastic shrinkage is not uniform in the concrete slab, which leads to the formation of tensile stress that further causes cracking.

In practice, hydraulic shrinkage is much more important than plastic shrinkage. Excess water evaporates, faster or slower, during the concrete hardening, resulting in the so-called hydraulic shrinkage, which causes the appearance of stress in concrete. Restrained hydraulic shrinkage may cause cracking or distorting elements of concrete structures.

The available data from the literature as well as own research show that the rule of shrinkage is not possible to determine as well as some general conclusion, so shrinkage for each concrete mixture should be carefully monitored.

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