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TESTING THE STRENGTH OF CONCRETE MADE FROM RAW AND DISPERSION-TREATED CONCRETE RECYCLATE BY ADDITION OF ADDITIVES AND ADMIXTURES

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Abstract. Today, concrete comprises more than 65% of the total volume of building constructions. As it undergoes degradation and buildings require refurbishment, the volume of concrete increases at disposal sites. Due to a lack of non-renewable resources and due to high prices of energies, the reuse of concrete seems to be more than desirable. It is common knowledge that in concretes made from recycled concrete, the strengths of the original concretes can hardly be achieved. The addition of dispersion additives and mineral admixtures into the freshly mixed concrete can contribute to improving the mechanical properties of concretes made from recycled concrete. Potential composite action of the recyclate, mineral admixtures and dispersion additives in increasing the compressive strength of concretes made from recycled concrete remains to be a question.

Keywords: recycling, concrete recyclate, epoxy dispersion, penetration, slag, fly ash, microsilica.

1. Introduction

This paper draws on the research published so far in the field of application of recycled materials in the building industry (Klimešová *et al.* 2001). It aims to contribute to the enhancement of the existing findings with new experience in using waste admixtures. These admixtures, either pure or combined with modern waterborne epoxy dispersion, can be used in the production of concrete with a partial replacement of natural aggregate with concrete recyclate (Stehlík 2010a). Epoxy dispersions can both improve the adhesive properties of the cement paste which binds the concrete recyclate and, when applied to the dry recyclate, positively influence its high absorption capacity (Novák *et al*. 2006; Henning, Lach 1983). The addition of fly ash, slag, microsilica, also in combination with epoxy dispersion, is another variant of the possible improvement of mechanical properties of concrete made from concrete recyclate. The aim of this paper is to examine the expected changes in mechanical properties of the samples of both raw and dispersion-treated concrete recyclate when applying alternative additions and admixtures. Standard concrete cubes with the dimensions of 150×150×150 mm will be tested for the compressive strength after 28-day maturing in a humid environment. The resulting values of strengths will be compared with the reference set, focusing on the monitored changes in the strengths of concrete after adding different admixtures with or without the addition of polymer dispersion. The determination of the compressive strength of concrete made from concrete recyclate was chosen on purpose as, so far, most institutions have focused on modifying mainly the physical properties of concrete made from concrete recyclate, such as contractibility, frost resistance, water permeability coefficient, leachability, etc. (de Brito, Robles 2010; Kou *et al.* 2011). In fact, however, increasing the strength class of concrete made from concrete recyclate is the condition not only for a more effective reuse of concrete recyclate, e.g. in the construction concretes, but also, indirectly, for increasing the life of the structure (Šmerda *et al.* 1999; Vavřín, Retzl 1987).

2. Experimental setup

The following materials were necessary for testing the possibility to improve the mechanical properties of concretes made from recycled concrete: Cement CEM I 42.5 R, waterborne epoxy dispersion CHS Epoxy 160V55 + hardener Telalit 1261 (mixing ratio 100:11.5 by weight), slag, fly ash, industrial microsilica, fine and coarse natural dense aggregate and concrete recyclate. The most important component of the tests, concrete recyclate of fraction 0–16 mm, was supplied by the Dufonev, s.r.o. company. According to ČSN EN 206-1(Z3) Concrete – Part 1: Specification, performance, production and conformity (2008), it is the type 1 recycled aggregate (chips or sand made by crushing concrete only, the so-called broken concrete), which can only be used in concretes made from recycled aggregate. Determined in accordance with ČSN EN 1097-6 Tests for mechanical and physical properties of aggregate – Part 6: Determination of particle density and water absorption

(2001), the absorption capacity of the concrete recyclate corresponded to the 10.5% part by weight after 10 minutes. However, the permissible standard value of absorption capacity of the type 1 concrete recyclate is only 10% part by weight after 10 minutes. The grading curve in Fig. 1 shows approx. a 19% content of fraction 0–4 mm, which marginally complies with the conditions for generally applicable concretes made from concrete recyclate (Pytlík 2000; Sun, Jiang 2010). Thus, as the absorption capacity and granulometry of the tested recyclate were not ideal, the recyclate was experimentally penetrated with epoxy dispersion.

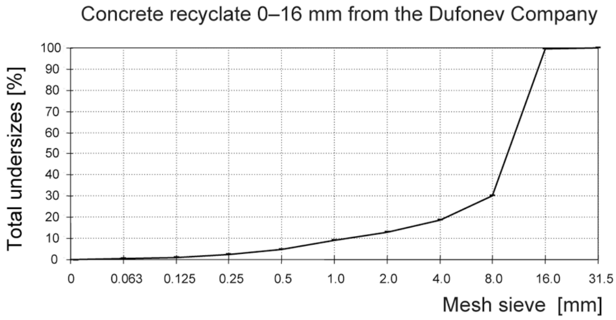

Fig. 1. Grading curve of natural concrete recyclate

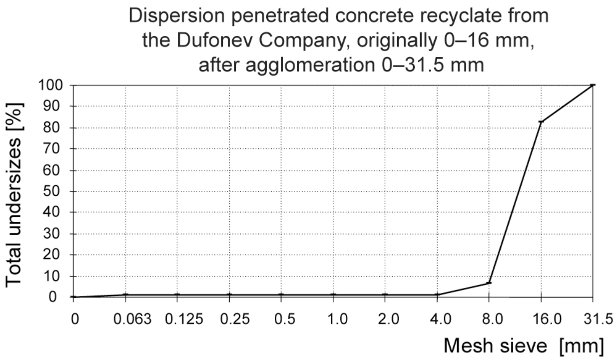

Fig. 2. Grading curve of dispersion-penetrated concrete recyclate

The penetration treatment of raw concrete recyclate, fraction 0–16 mm, was carried out for the purpose of agglomerating the unsuitable fine fraction of 0–4 mm with the coarse fraction of 4–16 mm, and for the purpose of lowering the absorption capacity below the standard of 10%.

Before the actual penetration of the waterborne epoxy dispersion into the surface of recycled concrete, it was necessary to dry the recyclate up and, after cooling down, to dip it into the water-diluted dispersion (dispersion:water = 2:1 by volume), mixed in advance with a prescribed amount of the hardener (Novák *et al.* 2006; Sebök 1985). The excess liquid dispersion (including part of the admixed fine particles) was removed using a standard sieve with a mesh size of 0.5 mm. Dispersion-coated recycled concrete was placed on a PE sheet (see Fig. 4) for penetration, drying out and hardening of the thin surface emulsion film. Fig. 3 presents the difference between the granularity of the recyclate penetrated with epoxy dispersion (left) and that of the raw concrete recyclate containing approx. 19% of fine fraction 0–4 mm (right). In the case of the dispersion-treated recyclate it is apparent that the liquid dispersion absorbs the majority of fine fraction during mixing, and that after the mutual bonding of the dispersion-coated particles and after their hardening, greater agglomerates, fraction 4–31.5 mm, arise (Šauman 1965). The agglomeration is apparent from the grading curve of penetrated recyclate in Fig. 2.

Fig. 3. Dispersion-penetrated and subsequently agglomerated Dufonev recyclate, fraction 0–31.5 mm (left); original raw Dufonev recyclate, fraction 0–16 mm (right)

Fig. 4. Freshly dispersion-penetrated Dufonev recyclate, fraction 0–31.5 mm, spread to dry up and harden on a PE sheet

Table 1 shows the overview and marking of the reference concrete mixture (dense aggregate) and of the concretes made from raw and penetrated concrete recyclate including additives and admixtures. Table 2 contains formulations for reference concrete made from dense coarse aggregate (Form. R1), for basic concrete made from the raw (untreated) concrete recyclate, fraction 0–16 mm (Form. R2 and the basis of formulations R3-R6) and for concrete made from penetrated recyclate (Form. R7). Besides, concrete made according to formulation R3 contains an admixture of 30% of ground blast-furnace slag of the mass of cement, R4 contains 30% of fly ash (Bai, Gailius 2009), R5 10% of industrial microsilica (Antonovič *et al.* 2010) and R6 a mixed admixture of 30% of fly ash and 10% of microsilica. Each of the concrete mixtures marked R1-R7 was prepared in two variants, without adding dispersion, and with 12% water-based epoxy dispersion added into the original concrete mixture (Schulze *et al.* 1990). The composition of R1 concrete mixture (dense aggregate) was prepared for strength class C 35/45, formulations R2-R7 (recycled concrete) for strength class C 25/30, both at a consistency of S1 (slump 10–40 mm according to EN 12350-2 (2009)). We made 6 test cubes according to each formula (both with and without adding epoxy dispersion), which is 36 cubes in total. The first three cubes from mixtures R1-R6 were made from concrete without adding epoxy dispersion, then the dispersion with hardener was added at the amount of 12% of the mass of cement and the remaining mixture was homogenized again.

Table 1. Types and marking of concretes of seven sets of test cubes

Basic composition of concrete mixture	Admixture and additive	Number of cubes	Marking of mixture	Slump test acc. to EN 12350-2
Reference	–	3	R1	S1
	12% epoxy dispersion	3	R1E	S3
From raw concrete recyclate	–	3	R2	S1
	12% epoxy dispersion	3	R2E	S3
	30% slag	3	R3	S1
	30% slag + 12% epoxy dispersion	3	R3E	S3
	30% fly ash	3	R4	S1
	30% fly ash + 12% epoxy dispersion	3	R4E	S3
	10% silica	3	R5	S1
	10% silica + 12% epoxy dispersion	3	R5E	S3
	30% fly ash + 10% silica	3	R6	S1
	30% fly ash + 10% silica + 12% epoxy dispersion	3	R6E	S3
From penetrated concrete recyclate	–	3	R7	S1
	12% epoxy dispersion	3	R7E	S3

The addition of dispersion caused a decrease in consistency from S1 to S3 degree of slump (100–150 mm). The amount of 12% of the cement mass is the limit dose, which, according to both the previous results of our own (Novák *et al.* 2008) and those of other researchers (Ohama 1995) is not sufficient to markedly decrease the compressive strength of PCC concretes. The dispersion used complies with the requirements of the Directive 2004/42/EC of the European Parliament and of the Council on the limitation of emissions of VOC (volatile organic compounds) (2004). Table 2 gives three basic fractions of coarse aggregate for preparing the reference concrete. The concrete made from recycled concrete was prepared by replacing the coarse aggregate from Olbramovice, fraction 8–16 mm, with both raw and penetrated concrete recyclate. Mixtures marked R3 and R3E to R6 and R6E were modified by adding slag, fly ash and microsilica at amounts according to Table 1.

Table 2. Formulation of concrete batch

Formulation R1 Reference formulation, using natural coarse aggregate Olbramovice (Czech Rep.) 8–16 mm	
CEM I 42.5 R	300 kg/m^3
0–4 natural fine aggregate Bratčice	760 kg/m^3
4–8 natural coarse aggregate Tovačov	228 kg/m^3
8–16 natural coarse aggregate Olbramovice	912 kg/m^3
water	136 kg/m^3
Formulation R2 + base R3 – R6 100% coarse aggregate of fraction 8–16 mm replaced by natural concrete recyclate 0–16 mm	
CEM I 42.5 R	300 kg/m^3
0–4 natural fine aggregate Bratčice	760 kg/m^3
4–8 natural coarse aggregate Tovačov	228 kg/m^3
0–16 natural concrete recyclate	690 kg/m^3
water	159 kg/m^3
Formulation R7 100% coarse aggregate of fraction 8–16 mm replaced by dispersion penetrated concrete recyclate 0–31.5 mm	
CEM I 42.5 R	300 kg/m^3
0–4 natural fine aggregate Bratčice	760 kg/m^3
4–8 natural coarse aggregate Tovačov	228 kg/m^3
0–31.5 penetrated concrete recyclate	690 kg/m^3
water	148 kg/m^3

3. Results and discussions

The change in compressive strengths of concretes made from raw and penetrated concrete recyclate after adding various admixtures – and as a variant epoxy dispersion – is graphically presented by Fig. 5. It should be noted that the test cubes were placed in a humid environment for 28 days after unmoulding – the 12% content of epoxy dispersion excludes their placement in water because of a possible leaching.

As regards the dispersions of penetrated concrete recyclate, the following was found out:

- The surface layer of type 1 concrete recyclate penetrated with dispersion lowers the original critical absorption capacity of the untreated recyclate from 10.5% to the favourable value of 6%. The requirement of ČSN EN 206-1/Z3 (2008) on the maximum absorption capacity after 10 minutes is 10%. The recyclate is penetrated using a modern solvent-free dispersion CHS Epoxy 160V55 + hardener Telalit 1261;

- The lowering of absorption capacity of type 1 concrete recyclate by penetration from 10.5% to 6% influences the resulting compressive strength of concrete made from concrete recyclate only a little – by 4% (see Fig. 5, Form. R2 vs. R7).

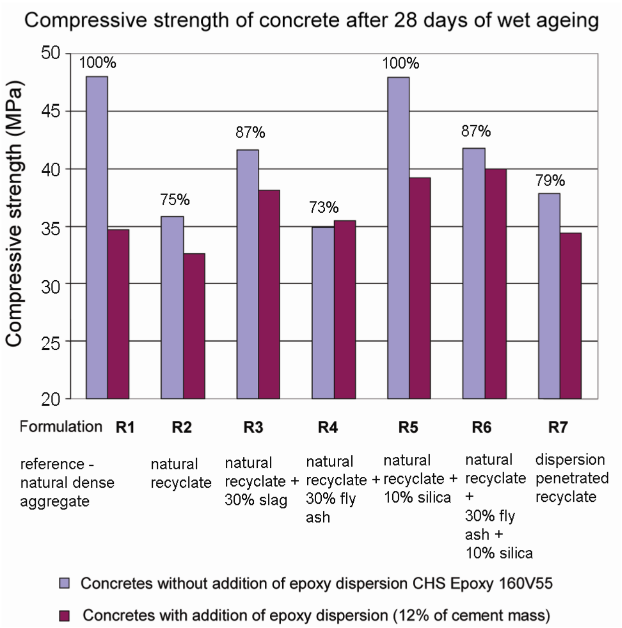

Fig. 5. Change in compressive strengths of concretes made from raw and dispersion-penetrated concrete recyclate after adding additives and admixtures

On the basis of the comparison of the strengths of concretes with raw and dispersion-treated concrete recyclate with the strength of reference concrete containing natural aggregate, it is possible to arrive at the following conclusions:

- Compressive strengths of concrete made from natural and penetrated concrete recyclate, compared to the strength of reference concrete made from natural aggregate, are lower by approx. 1/4 to 1/5 (see Fig. 5, Form. R1, R2 and R7). This is caused by a lower strength of concrete recyclate compared to that of natural dense aggregate;
- The 10% admixture of microsilica increases markedly the strengths of concrete made from recycled concrete (Form. R5) up to the level of the reference concrete (Form. R1). Microsilica can bind the hydrating mastic cement with the surrounding aggregate better;
- The 30% admixture of blast-furnace slag increases the strength of concrete made from recycled concrete (Form. R3), but compared to microsilica, the increase is not so marked (Form. R5). This is caused by the size of slag grains which are substantially larger than those of microsilica;
- The influence of 30% addition of fly ash is negative (Form. R4), the compressive strength dropped to 73% of the strength of reference concrete (Form. R1). This result is surprising because in general, fly ash increases the strength of concretes made from natural aggregate;
- The combined admixture of 30% of fly ash and of 10% of microsilica (Form. R6) did not come up to expectations, the 28-day strengths being lower compared to the mere addition of 10% of microsilica (Form. R5). Here again, we can see an unexpectedly negative influence of fly ash on the increase of strength of concrete made from recycled concrete;
- The addition of 12% epoxy dispersion (Form. R1E, R2E,…, R7E) lowers the 28-day strength of both the reference concrete and the concretes made from recycled concrete. The fault is with the increase in fluidity of the concrete mixture after adding the dispersion for the manufacture of the second triad of concrete cubes, when the slump increased from grade S1 to grade S3.

4. Conclusions

On the basis of the results measured and of the results obtained from similar research (Stehlík *et al.* 2010b), it is possible to conclude that the improvement of the compressive strength of concretes made from recycled concrete can be achieved by a suitable admixture on a mineral basis; best results have been achieved by adding 10% of microsilica. However, in the competitive environment of the industrial production of concrete it is hardly tenable to maintain the compressive strength of concretes made from recycled concrete at the same level as that of reference concrete made from natural aggregate by adding expensive microsilica. In the Czech Republic the price of some mined aggregates of lower quality (approx. 12€/1m^3) approaches the price of concrete recyclate (approx. 8€/1m^3). Therefore, the production of higher-quality concretes from recycled concrete without a potential subsidy is not economically advantageous. We can thus only speak about ecological advantage. In the case of improving the concrete recyclate with dispersion penetration or improving the concrete made from concrete recyclate with a dispersion additive, the situation is even worse. The following facts speak for the dispersion: the penetration of concrete recyclate with epoxy dispersion improves markedly its physical properties and thus contributes to the lowering of water permeability coefficient of the mixed concrete (Stehlík *et al.* 2010a). The dispersion admixture dosed into the mixing water improves the workability of concrete mixtures, speeds up the start of their initial strengths, improves their adhesive and deformation characteristics. Facts against: the penetration of raw recyclate and addition of dispersion admixture into the mixing water do not markedly increase the compressive strength of maturing concretes, and the price of epoxy dispersion is too high. The treatment of 1m^3 of concrete recyclate with penetration requires dozens of litres of 50% water solution of the dispersion, the production of 1 m^3 of concrete made from raw recyclate requires adding approximately 100% of epoxy dispersion (approx. 4€/1l in CR) into the mixing water. Thus, the future of dispersion-improved concretes made from concrete recyclates is probably in special applications, e.g. water-resistant or carbonation-resistant concretes of lower strength classes. The new generation of modern solvent-free waterborne epoxy dispersions can also be successfully used for the surface impregnation of an already hardened concrete (Novák *et al.* 2008; Richardson 1988; Matoušek, Drochytka 1998), where it is possible to achieve a maximum protection against the negative impact of moisture and acid gases.

The contemporary state of production technology requires that the recycled concrete the strength of which is lower than that of fresh concrete should be used in structures of minor importance. However, the results obtained in the research presented here seem to be fairly optimistic. Hopefully they will help to shift the use of the originally inferior-quality concrete made from concrete recyclate towards the special or high-strength demanding construction applications. This will however require further tests of physical and durability properties. These tests should contribute to understanding the surface structure and thereby to prolonging the life of concretes made from concrete recyclate. Here it would be convenient to draw on the research reports published earlier (Gómez-Soberón 2002; Zaharieva *et al.* 2003). Further research might concentrate on testing the surface permeability for gases using the Torrent method, testing water permeability using GWT or ISAT, testing diffusion properties, or on accelerated carbonation testing.

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