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Dynamic moduli of cement paste with different kinds of recycled concrete admixtures

Z Prosek[1,2], J Trejbal[1], P Tesárek[1] and J Ďureje[1]

[1] Czech Technical University in Prague, Faculty of Civil Engineering, Prague, 166 29, Czech Republic

[2] Czech Technical University in Prague, University Centre for Energy Efficient Buildings, Buštěhrad, 273 43, Czech Republic

E-mail: zdenek.prosek@fsv.cvut.cz

Abstract. This article deals with using recycled concrete powder as a partial replacement for cement. In particular, we focus on mechanical properties of cement pastes containing recycled concrete powder. We used three different recycled materials. The first recycled concrete powder was obtained from the PB2 and the SB8 railway sleepers, the second one was from the drainage gutter and the third one was from the monolithic construction of a pillar. All recycled materials were milled by LAVARIS Ltd. at high-speed milling process. Investigated mechanical properties were the dynamic modulus of elasticity and the dynamic shear modulus and were obtained by a non-destructive method: the resonance method. The dynamic modulus of elasticity and the dynamic shear modulus were examined and compared after 7, 14, 21 and 28 days of mixture curing. Results obtained from these materials were compared with the reference material.

1. Introduction

Nowadays, recycled concrete is used for backfilling and landscaping or underlying road layers [1]. Another possibility is to use recycled concrete as a new aggregate. This option is possible if precise sorting and recycling of old concrete are used [2]. Only the fraction larger than 1 mm is used in this recycling. However, the problem arises when processing a very fine fraction (<1 mm) of recycled concrete. The processing of this very fine fraction brings many complications and pitfalls with it and, unfortunately, other financial costs. One option is thermal activation of an old cement paste. The utilization of recycled concrete by thermal activation have been spelled out clarified within various researchers, as showed e.g. in [3, 4]. Due to high demands on energy consumption and CO_2 production, it is particularly suitable for sustainable and environmentally friendly methods where the very fine fraction of recycled concrete is used in its raw form [5, 6].

Unlike the mentioned researchers, we focused directly on mechanical activation of old cement pastes. The article deals directly with the use of possible hydration potential of micronized concrete. The micronizing of the old cement paste into fine particles results in uncovered unhydrated clinker minerals, which can further hydrate upon contact with water [7]. For this mode of activation, a high-speed grinding method was used. The high-speed milling process has been successfully used for micronizing of marble sludge [8].

The possibility of replacing the binder with a fine fraction of recycled concrete was dealt with in several works [9, 10], directly works deals with replacing the binder in mortar mixes up to 25 wt. %. As a result, the compressive strength was reduced 15 to 20%, the difference in the values may be due to the type of old concrete. The dynamic module was not solved directly, but its value is directly dependent on the compressive strength of the cement composite [11].

2. Materials and specimens

Cement pastes were composed of Portland cement CEM I 42.5R (Radotín, Czech Republic) and micronized recycled concrete. Cement was replaced by the micronized recycled concrete by the amount of 50 wt. %, (Table 1). The selected ratio of cement and recycled material (1:1) was chosen to highlight the differences between single-use recycled materials. Three different types of recycled concrete were used. The first recycled concrete was obtained from the PB2 and the SB8 railway sleepers, the second one was from the drainage gutter and the third one was from the monolithic construction of a pillar. All recycled materials were in first pre-crushed to do fraction 0–1 and then milled. Recycled concrete was micronized using a high-speed mill from Lavaris Ltd. (Libčice, Czech Republic) for its mechanical activation of recycled concrete. The result was micronized material from railway sleepers (MRS), the drainage gutter (MDG) and the construction of a pillar (MCP). The water ratio is described as water to cement and the micronized recycled concrete weight ratio. The water ratio was equal to 0.35. The workability of the fresh mixture was measured within the production of specimen. The consistency of fresh mixtures was determined by means of a flow expansion test after 10 (d_{10}) and 20 (d_{20}) impulses (Table 1).

Mixtures made according to Table 1 were molded to rectangular forms having inner dimensions equal to 40 × 40 × 160 mm. These specimens were kept in the forms for 24 h at a room temperature of 22°C. All testing mixtures included 6 specimens. After demolding, these samples were stored in a water bath for 28 days.

Table 1. Composition of the mixtures.

Set/ Material	Cement (g)	Micronized concrete (g)	Water ratio (-)	Flow expansion test d_{10} (mm)	Flow expansion test d_{20} (mm)	Bulk density (kg·m^{-3})
Ref. CEM	3,000	0	0.35	160	190	2,052 ± 4
MRS	1,500	1,500	0.35	110	120	1,957 ± 3
MDG	1,500	1,500	0.35	110	120	1,951 ± 11
MCP	1,500	1,500	0.35	105	115	1,981 ± 2

3. Experimental methods

The characterization of recycled concrete was carried out with a number of experimental approaches in order to investigate all relevant features. In the initial stage of the research, the micronized recycled concrete was examined from the perspective of material composition by X-ray fluorescence technique (XRF). The result of XRF was chemical composition of recycled concrete. It was determined 48 elements among which were also measured common harmful heavy metals.

The pH value was determined from aqueous extracts (in a weight ratio of 1: 100) after 24 hours at a room temperature (25 ± 1°C) by using pH meter (from Monokrystaly a.s.). This type of pH meter is suitable for fast measurement with a deviation of a value about 0.2.

The particle size distribution was determined by devices Laser Particle Sizer Fritsch ANALYSETTE 22 NanoTec. The device was capable of measuring sizes ranging from 0.01 mm up to 2.1 mm and used the combination of two lasers. The first laser was infrared and was used for large particles. Small particles were measured by green laser. The particle size distribution was performed using wet dispersion.

Values of the dynamic shear modulus and the dynamic modulus of elasticity of the samples were determined after 7, 14, 21 and 28 days. The resonance method was applied for the detection of these moduli. Six samples with dimensions 40 × 40 × 160 mm were examined. Measurements of the dynamic moduli were carried out by the instrument from Brüel & Kjær. Dynamic moduli were evaluated from basic natural frequencies by using standard equations for the prismatic sample. The dynamic modulus of elasticity was achieved by using the basic longitudinal natural frequency of samples and basic flexural natural frequency of samples. An acceleration transducer was placed on the surface of the sample in the center of the vertical side perpendicular to the length of the sample and the hammer hits were performed on the center of the opposite surface, in the case of the longitudinal natural frequency. The acceleration transducer was placed on the edge of the top side of the surface sample and hammer hits were performed on the edge of the same side of the sample, in the case of the flexural natural frequency. Samples were supported by a smooth and a flexible block at the midpoint of its length, which is the major longitudinal nodal location, in the case of the longitudinal natural frequency. Samples were supported by two smooth and flexible blocks at the major bending nodal lines, which were located at a distance of 0.224 × length of the sample from each end of the sample, in the case of the flexural natural frequency. The dynamic shear modulus was achieved by using the basic torsional natural frequency of the sample. The acceleration transducer was placed on the surface of the sample in the corner of the vertical side parallel to the length of the sample and hammer hits were performed diagonally on the same side. Samples were supported in the same way as in the case of measuring of the longitudinal natural frequency of samples [8].

4. Results and discussion

The result of chemical composition is shown in Table 2. Table 2 shows percent weight of individual oxides with a content greater than 0.5%. Results showed that the micronized drainage gutter (MDG) had a high volume of silica, from the reason of the high volume of silica aggregate in fraction 0-1 mm and the low volume of the cement matrix with unhydrated clinker minerals. The other two recycled concrete, the micronized railway sleepers (MRS) and the micronized construction of a pillar (MCP), exhibit the same amount of the cement matrix, making it more suitable for possible using of recycled concrete powder as a partial replacement for cement. None of recycled materials does contain an excessive amount of harmful components for future application in concrete. According to composition, waste micronized recycled concrete can be used as a partial replacement for cement.

Table 2. Chemical composition of tested materials.

	Percent weight of individual oxides [%]			
Oxides	CEM I 42.5R	MRS	MDG	MCP
CaO	65.76	26.85	16.89	19.90
SiO_2	16.85	51.63	50.71	54.23
SO_3	4.85	1.52	0.79	1.37
Al_2O_3	3.61	14.95	16.82	12.92
Fe_2O_3	3.34	-	4.85	4.36
Na_2O	2.88	1.92	3.26	2.20
MgO	2.31	2.92	3.00	2.43
K_2O	-	-	3.45	2.02

The particle size distribution was shown in Figure 1. Portland cement with fraction 0–200 microns had mean grain size of 12.8 microns and 90 wt. % of grains were smaller than 44.1 microns. The micronized railway sleepers (MRS) with fractions 0–130 µm had mean grain size of 12.4 microns and 90 wt. % of grains were smaller than 45.4 microns. The micronized drainage gutter (MDG) with fractions 0–80 µm had mean grain size of 7.4 microns and 90 wt. % of grains were smaller than 22.3 microns. The last recycled concrete micronized construction of a pillar (MCP) with fractions 0–40 µm had mean grain size of 3.1 microns and 90 wt. % of grains were smaller than 11.5 microns. The all three materials were milled by the same disintegrator and had different mean values of grains size, this is due to the different composition of the recycled concrete (size and amount of silica aggregate, water-cement ratio, kind of cement) and thus also different strength and resistance to the milling process.

Results showed that all recycled concrete is finer or same as the reference Portland cement. The high speed milling process could cause crushing of cement grains, which uncovered unhydrated clinker minerals. It is possible at the same time, that micronized concrete can be a binder and a microfiller.

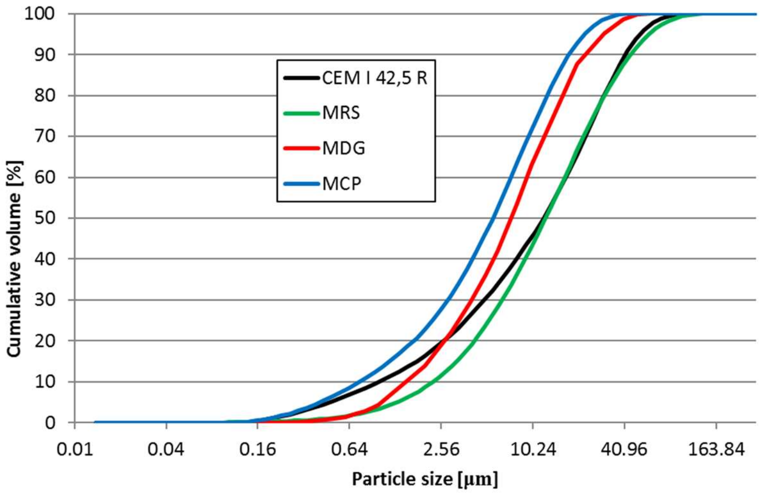

Figure 1. Particle size distribution of tested materials.

Values of pH have been monitored for the research to provide hydration properties. The pH values of recycled concrete were compared with the pH value of Portland cement (12.54). The value of pH was 11.68 in the case of micronized railway sleepers (MRS), 11.99 in the case of the micronized drainage gutter (MDG) and 12.52 in the case of the micronized construction of a pillar (MCP). Recycled concrete has a similar pH value, so it does not seem necessary to solve it in this case.

Results from the resonance non-destructive method are shown in Figure 2 and Figure 3 and showed differences between values of the moduli at the 7, 14, 21 and 28 days. Differences between the values after 21 and 28 days were in the size of standard deviations. It can be stated that after 21 days, a minimal change of the dynamic modulus of elasticity and the dynamic shear modulus occurred. The average value of moduli of the reference samples after 28 days were 25.31 ± 0.08 GPa in the case of the modulus of elasticity (Figure 3) and 9.90 ± 0.09 GPa in the case of the shear modulus (Figure 2). The samples with the micronized construction of a pillar (MCP) had the largest value among samples with the recycled material of the dynamic shear modulus, namely 7.82 ± 0.13 GPa (Figure 2) and the dynamic modulus of elasticity, namely 19.19 ± 0.23 GPa (Figure 3). The samples with the micronized drainage gutter (MDG) had the lowest value of the dynamic shear modulus, namely 7.30 ± 0.01 GPa (Figure 2) and the dynamic modulus of elasticity, namely 18.55 ± 0.08 GPa (Figure 3).

The results obtained are in accordance with the results of the authors [9, 10, 11] The type of used old concrete influences the resulting mechanical properties of the cement composite. The concrete with high strength (pillar, sleepers) has a positive effect on the mechanical properties of the resulting cement composite.

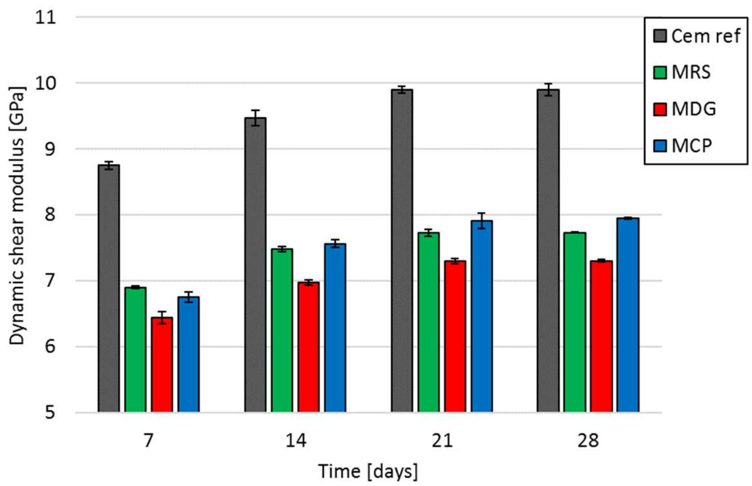

Figure 2. Comparison of the dynamic shear modulus (with standard deviation).

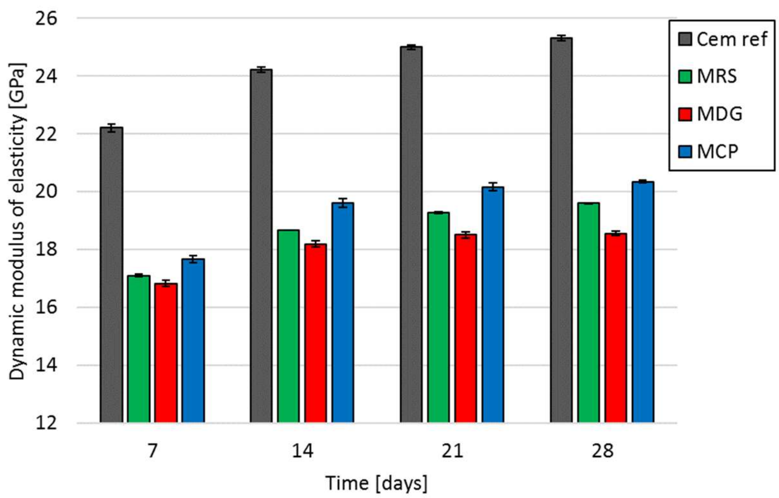

Figure 3. Comparison of the dynamic modulus of elasticity (with standard deviation).

5. Conclusion

This article deals with the influence of micronized recycled concrete on mechanical properties of resulting cement pastes. Researched cement pastes were composed of Portland cement and three different recycled materials in a ratio of 50/50. The first recycled concrete powder was obtained from the PB2 and the SB8 railway sleepers, the second one was from the drainage gutter and the third one was from the monolithic construction of a pillar. Based on results, it can be concluded that:

- None of recycled materials does contain excessive amount of harmful components for future application in concrete.
- The high speed milling process cause crushing of cement grains, which uncovered unhydrated clinker minerals.
- The average value of the dynamic modulus of elasticity and the dynamic shear modulus were unchanged between 21 and 28 days.
- For 50 wt. % of recycled concrete, the dynamic modulus of elasticity decreased by approximately 20%. The largest value of the dynamic modulus of elasticity had samples with recycled concrete from the micronized construction of a pillar (MCP) and the lowest from

the micronized drainage gutter (MDG). The difference between these values was approximately 10%.

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