PAPER • OPEN ACCESS

Evaluation of the size effect of waste tyre rubber particles on properties of lightweight rubber concrete

To cite this article: M Záleská *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **596** 012043

IOP Conf. Series: Materials Science and Engineering **596** (2019) 012043 doi:10.1088/1757-899X/596/1/012043

Evaluation of the size effect of waste tyre rubber particles on properties of lightweight rubber concrete

M Záleská[1], M Pavlíková[1], D Čítek[2] and Z Pavlík[1]

[1] Department of Materials Engineering and Chemistry, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29 Prague 6, Czech Republic
[2] Department of Experimental Methods, Klokner Institute, Czech Technical University in Prague, Šolínova 7, 166 08 Prague, Czech Republic

E-mail: martina.zaleska@fsv.cvut.cz

Abstract. Due to the increasing amount of waste tyres and also to their properties, it is necessary to look for suitable ways for their recycling. For production of rubber concrete, the crushed tyre rubber of fraction 0/4 and 4/8 was used for partial substitution of silica sand at the rate of 10 % by mass. For comparison, a reference concrete without rubber aggregate was also studied. Both natural and rubber aggregate were first assessed in terms of their physical parameters and thermal transport and storage properties. Evaluation of produced lightweight rubber concrete included measurement of basic physical properties, strength tests, and microstructural analysis. Thermal properties were studied from dry to fully water saturated state. The experimental results showed that concrete with a small amount of rubber aggregate had improved thermal insulation performance and can serve as an eco-friendly material for structural applications in civil engineering.

1. Introduction

Over 25 million tons of end-of-life tyres are generated per year all over the world and 31 % of this amount is landfilled, stockpiled or its treatment is unknown as is reported by World Business Council of Sustainable Development [1]. The valorisation of this waste tyre into cement concrete could be a partial solution for relieving their negative environmental impact [2]. Recently, many studies have been carried out on rubber concrete containing tire rubber-based aggregate as a replacement of fine or coarse natural aggregate [3-5]. Generally, researchers reported the reduction of strength parameters, weight unit and thermal conductivity of rubberized concrete in comparison with concrete prepared without rubber [6-8]. In order to evaluated the size effect of rubber-based aggregate particles on the rubber concrete properties, this paper is focused on the use of two size fractions of tyre rubber, which replaced the fine, coarse, and both fine and coarse natural aggregate in the weight ratio of 10 %.

2. Experimental

The materials used for preparation of test specimens were cement, water and both coarse and fine natural and rubber aggregate. Portland slag cement CEM II/A-S 52.5 N (Spenner Zementwerk Berlin GmbH & Co. KG, Germany) was used as a binder. Rubber particles, the size fraction of 0/4 mm and 4/8 mm (figure 1), were obtained from mechanical crushing of waste tyre rubber. Silica sand as natural aggregate of 0/4 mm and 4/8 mm fraction comes from the gravel-pit Dobříň, Czech Republic. Four concrete mixtures were prepared to study the rubber size effect. The rubber particles were used to replace the fine (mix CR4), coarse (mix CR8) and both fine and coarse (mix CR4+8) natural aggregate

IOP Conf. Series: Materials Science and Engineering **596** (2019) 012043 doi:10.1088/1757-899X/596/1/012043

in the weight ratio of 10 wt%. The reference concrete without rubber (CRef) was prepared as well. Water to cement ratio (w/c) was 0.5 for all tested mixtures. Table 1 presents the composition of concrete specimens with incorporated rubber aggregate.

Table 1. Mix proportions of rubber concrete.

Notation	Mass (g)						w/c
	Cement	Sand 0/4	Sand 4/8	Rubber 0/4	Rubber 4/8	Water	
CRef	450	675	675	-	-	225	0.5
CR4	450	540	675	135	-	225	0.5
CR8	450	675	540	-	135	225	0.5
CR4+8	450	607.5	607.5	67.5	67.5	225	0.5

Figure 1. Rubber aggregate.

There were prepared prismatic samples with dimension of 40 × 40 × 160 mm and cubic samples with side dimension of 100 mm, which were after casting left at highly humidity environment (RH ≥ 98 %) and temperature (23 ± 2) °C. After 24 h samples were demolded and cured for next 27 days in water.

2.1. Characterization of rubber aggregate

The particle size analysis was made for both natural and rubber aggregate using the standard sieve method. There were used sieves with mesh dimensions of: 0.063; 0.125; 0.5; 1.0; 2.0; 4.0; 8.0 and 16.0 mm. The specific densities of aggregates were determined by automatic helium pycnometer Pycnomatic ATC (Thermo Scientific). In more detail were explored the thermal properties of both sand and rubber particles. Their thermal conductivity λ ($W \cdot m^{-1} \cdot K^{-1}$) and volumetric heat capacity C_v ($J\ m^{-3} \cdot K^{-1}$) as well as the powder density were measured in dependence on the compacting time because the compacted state of aggregate better reflects its performance in concrete structure. For compaction was used a high vibrating table VSB-15 (Brio). Thermal parameters were obtained using an ISOMET 2114 device (Applied Precision, Ltd.) working on a transient impulse method [9]. For the measurement, a needle probe was used.

2.2. Testing of rubber concrete

The hardened 28 days concrete samples were used for testing. The conducted tests included an optical microscopy analysis, assessment of structural, mechanical, thermal transport and storage properties.

An optical microscopy (digital light microscope VHX-200 D, Keyence) was used for study of hardened rubberized concrete microstructure.

The specific density was measured on the dried samples using a helium pycnometry (as described above). The bulk density was obtained on a gravimetric principle from measurement of the weight and dimensions of dried concrete specimens. The bulk density test was performed according to the standard EN 12390-7 [10]. The total open porosity was than calculated on the basis of specific and bulk density values. The relative expanded uncertainty of applied measuring method was approx. 5 %.

The flexural strength test was conducted following the standard EN 12390-5 [11]. The specimens were prism having dimensions of 40 × 40 × 160 mm. The compressive strength was determined according to the standard EN 12390-3 [12] on the fragments of samples from the flexural strength tests. The loading area was 40 × 40 mm. The relative expanded uncertainty of both compressive and flexural strength tests was 1.4 %. The dynamic Young´s modulus was measured using an ultrasonic device DIO 562 (Starmans Electronic) with working frequency of 50 kHz. Within this test, dried prism specimens of 40 × 40 × 160 mm were used. The expanded combined uncertainty of this test method was 1.5 %.

The thermal transport and storage properties of rubber concrete were investigated on the cubic specimens with the side dimension of 100 mm. Since the degree of saturation of concrete is one of the main factors influencing its thermal performance, the thermal conductivity and the volumetric heat capacity were determined in dependence on moisture content. An ISOMET 2114 device (see above) equipped with the surface probe was used for this measurement.

3. Results and discussion

The results of the sieve analysis performed for all used aggregates are shown in figure 2.

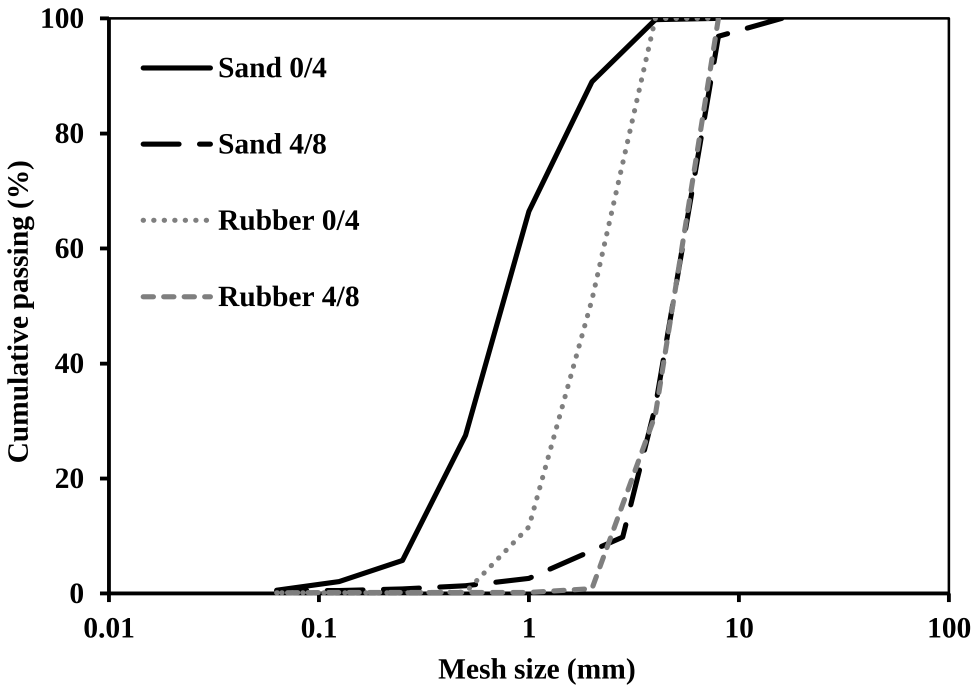

Figure 2. Sieve analysis of both natural and rubber aggregate.

In the table 2 there are introduced powder density and thermal properties of studied aggregates in dependence on the compacting time. Also aggregate specific density is presented.

Table 2. Physical and thermal properties of aggregates.

Aggregate	Specific density (kg·m^{-3})	Compaction time (s)	Powder density (kg·m^{-3})	λ (W·m^{-1}·K^{-1})	C_v (×10^6 J·m^{-3}·K^{-1})
Sand 0/4	2648	0	1604	0.306	1.522
		10	1775	0.390	1.561
		20	1775	0.399	1.570
		180	1799	0.403	1.576
Sand 4/8	2662	0	1408	0.315	1.404
		10	1539	0.348	1.420
		20	1581	0.369	1.426
		180	1603	0.389	1.443
Rubber 0/4	1154	0	468	0.093	0.326
		10	489	0.094	0.360
		20	506	0.095	0.380
		30	512	0.099	0.392
		180	524	0.100	0.412
Rubber 4/8	1174	0	445	0.095	0.253
		10	460	0.095	0.254
		20	465	0.096	0.256
		30	465	0.096	0.259
		180	465	0.096	0.262

We can see that both thermal conductivity and volumetric heat capacity of rubber were significantly lower compared to that of silica sand. This finding provides the assumptions for improved thermal insulation properties of rubber-containing concrete. Compaction reduced the air gaps between the grains of aggregate, which led to an increase in the thermal conductivity and volumetric heat capacity.

From the optical microscopy (figure 3), good cohesion between the rubber particles and cement matrix was clearly visible.

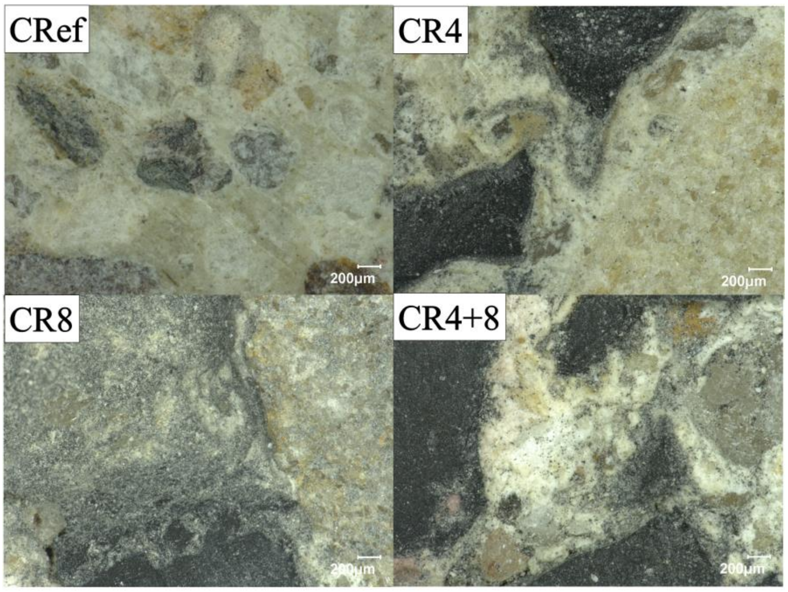

Figure 3. Optical microscopic images of studied concrete samples.

The bulk density, specific density, and the total open porosity of developed rubber concrete are given in table 3.

Table 3. Basic physical parameters of studied concrete samples.

Material	Specific density ($kg \cdot m^{-3}$)	Bulk density ($kg \cdot m^{-3}$)	Open porosity (%)
CRef	2453	2134	13.0
CR4	2281	1935	15.2
CR8	2249	1914	14.9
CR4+8	2281	1933	15.3

In comparison with the reference concrete, all rubberized concrete samples exhibited lower bulk density and specific density values, whereas the extent of differences between particular rubber concretes was not significant. The bulk density values of rubber concretes ranged from 1914 $kg \cdot m^{-3}$ to 1935 $kg \cdot m^{-3}$. They can therefore be classified into class LC 2.0 of lightweight concrete according to the standard EN 206-1 [13]. The open porosity of rubber concrete increased compared to reference sample. It can be explained by (i) the higher air entrapment during the preparation of the mixtures due to the presence of non-wetting rubber aggregate, (ii) the rubber particle shape, which differs from the spherical shape of the sand. Moreover, both size fractions of the rubber particles differ from each other, especially by the higher specific surface of the fraction 0/4, which can cause the higher porosity of concrete samples containing rubber fraction 0/4. Similar results in terms of density and porosity of rubber concrete were reported in literature [14].

The results of compressive strength, flexural strength, and dynamic Young´s modulus testing are summarized in table 4.

Table 4. Mechanical parameters of studied concrete samples.

Material	Compressive strength (MPa)	Flexural strength (MPa)	Young´s modulus (GPa)
CRef	61.5	6.8	39.0
CR4	28.0	5.7	18.1
CR8	26.0	5.1	17.0
CR4+8	31.0	4.9	18.6

The obtained mechanical resistance parameters were reduced with the addition of rubber aggregate. This finding was in line with previously published results [2], [5]. A decrease in compressive strength up to 54 %, 58 %, and 50 % for CR4, CR8 and CR4+8 respectively, compared to the reference concrete was observed. The CR4+8 concrete, where they were replaced both fine and coarse natural aggregate with rubber particles, exhibited the highest compressive strength and dynamic Young´s modulus among rubber concrete samples and, on the contrary, showed the lowest flexural strength. In [15] authors observed the worse performance in strength parameters for larger rubber particles from three sizes of rubber (3 mm, 0.5 mm, and 0.3 mm) used to replace of fine natural aggregate.

The thermal conductivity values measured for dry and fully water saturated samples are tabulated in table 5. It is clear from the results that 10% replacement of sand with rubber particles resulted in a decrease in the thermal conductivity value of 25-28 %. Part of the thermal conductivity reduction can be caused by the lower thermal conductivity of the rubber in comparison with the sand (see table 2) and part can be attributed to higher porosity of rubber concrete. It has been observed by Iqbal [3] that the concrete with 10 % of the rubber particles has reduced the thermal conductivity by 20 % relative to reference concrete. Hall et al. [16] reported a decrease in thermal conductivity of rubberized concrete compared to the reference concrete with an increase in a rubber substitution ratio and a mix design target slump value.

Table 5. Thermal conductivity of concrete samples in the dry and fully water saturated state.

Material	λ ($W \cdot m^{-1} \cdot K^{-1}$)	
	Dry	Saturated
CRef	1.78	2.38
CR4	1.31	1.82
CR8	1.28	1.90
CR4+8	1.33	1.97

Figure 4 shows the volumetric heat capacity in dependence on relative moisture content, which is defined as a ratio of the actual moisture content by weight to the saturated moisture content. The volumetric heat capacity decreased with the addition of rubber, the lowest value was obtained for the sample CR8. Since water is characterized by a higher volumetric heat capacity than concrete, the increase in water content in the samples also increased their volumetric heat capacity.

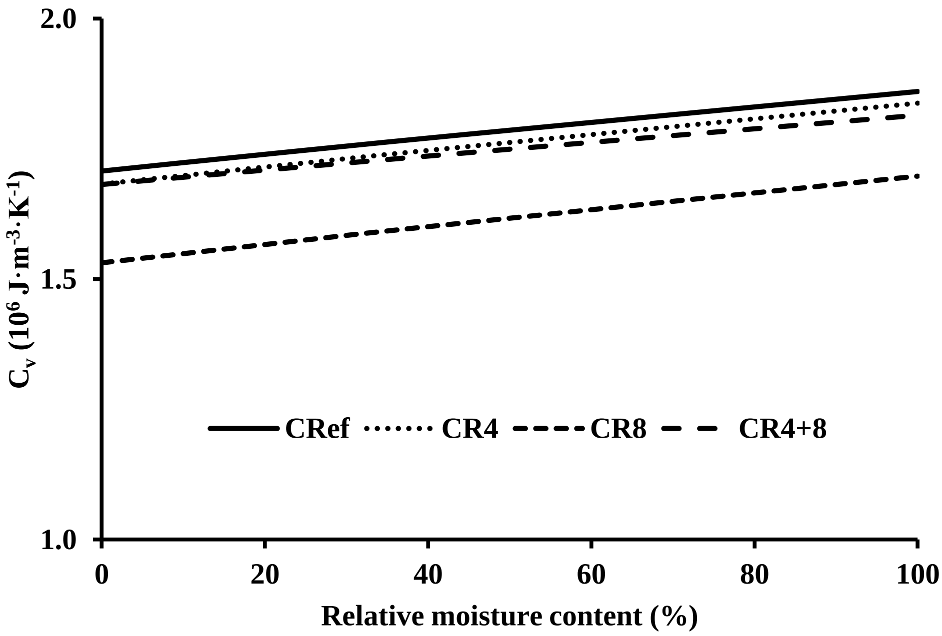

Figure 4. Moisture dependent volumetric heat capacity.

4. Conclusion

The experimental assessment of three types of rubberized concrete was presented. Modification of concrete with crushed tyre rubber decreased the mechanical resistance, unit weight and both thermal conductivity and volumetric heat capacity of investigated concretes. Moreover, the rubberized samples showed improved thermal-insulation properties even in the presence of moisture. Based on the obtained results it can be concluded that 10% substitution of fine, coarse, or both fractions of natural aggregate by crushed rubber particles of appropriate size, gave concrete with improved thermal-insulation performance that can find use in building industry in structural applications.

IOP Conf. Series: Materials Science and Engineering **596** (2019) 012043 doi:10.1088/1757-899X/596/1/012043

Acknowledgements
The authors gratefully acknowledge the financial support received from the Czech Science Foundation, under project No 17-04215S – Thermal insulation composites containing waste plastic based fillers. This research has been also partially supported by the Ministry of Education, Youth and Sport of the Czech Republic, under project No SGS17/166/OHK1/3T/11.

References
[1] WBCSD 2018 *Global ELT Management – A global state of knowledge on collection rates, recovery routes, and management methods* (www.wbcsd.org, accessed January 2019)
[2] Li G, Wang Z, Leung Ch K Y, Tang S, Pan J, Huang W and Chen E 2016 *J. Cleaner Prod.* **112** 797
[3] Iqbal M 2017 *Constr. Build. Mater.* **133** 516
[4] Aiello M A and Leuzzi F 2010 *Waste Manage.* **30** 1696
[5] Ganjian E, Khorami M and Maghsoudi A A 2009 *Constr. Build. Mater.* **23** 1828
[6] Thomas B S and Gupta R Ch 2016 *Renewable Sustainable Energy Rev.* **54** 1323
[7] Lv J, Zhou T, Du, Q and Wu H 2015 *Constr. Build. Mater.* **91** 145
[8] Pacheco-Torgal F, Ding Y and Jalali S 2012 *Constr. Build. Mater.* **30** 714
[9] Záleská M, Pavlíková M, Pokorný J, Jankovský O, Pavlík Z and Černý R 2018 *Constr. Build. Mater.* **180** 1
[10] EN 12390-7 Testing hardened concrete – Part 7: Density of hardened concrete, CEN, 2009
[11] EN 12390-5 Testing hardened concrete – Part 5: Flexural strength of test specimens, CEN, 2009
[12] EN 12390-3 Testing hardened concrete – Part 3: Compressive strength of test specimens, CEN, 2014
[13] EN 206-1 Concrete – Part 1: Specification, performance, production and conformity, CEN, 2014
[14] Girskas G and Nagrockienė D 2017 *Constr. Build. Mater.* **140** 36
[15] Su H, Yang J, Ling T Ch, Ghataora G S and Dirar S 2015 *J. Cleaner Prod.* **91** 288
[16] Hall M R, Najim K B and Hopfe K 2012 *Appl. Therm. Eng.* **33-34** 77