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Application of Glass Fiber Waste Polypropylene Aggregate in Lightweight Concrete – thermal properties

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Abstract. Actual paper focus on thermal properties of a sustainable lightweight concrete incorporating high volume of waste polypropylene aggregate as partial substitution of natural aggregate. In presented experiments a glass fiber reinforced polypropylene (GFPP) which is a by-product of PP tubes production, partially substituted fine natural silica aggregate in 10, 20, 30, 40 and 50 mass %. Results were compared with a reference concrete mix without plastic waste in order to quantify the effect of GFPP use on concrete properties. Main material physical parameters were studied (bulk density, matrix density without air content, and particle size distribution). Especially a thermal transport and storage properties of GFPP were examined in dependence on compaction time. For the developed lightweight concrete, thermal properties were accessed using transient impulse technique, where the measurement was done in dependence on moisture content (from the fully water saturated state to dry state). It was found that the tested lightweight concrete should be prospective construction material possessing improved thermal insulation function and the reuse of waste plastics in concrete composition was beneficial both from the environmental and financial point of view.

1. Introduction

The energy performance of a building is becoming increasingly important, because of environmental restrictions and rising costs of fuel end energy. Environmental aspects of constructions are more and more required by society nowadays. In order to design buildings with sufficient thermal attributes and optimum energy performance, specific attention must be paid not only to the design of building envelopes, but also to the thermal insulation of buildings subsoil [1]. To obtain buildings with high thermal resistance and sufficient thermal stability, the use of materials with suitable thermal insulation properties should be taken into account. The large growth of plastics consumption and consequently of plastic waste, requires new forms of recycling, avoiding landfill disposal [3]. In recent years in Europe, plastics recycling have increased to almost 30%. However landfilling and energy recovery still constitutes a large part of plastic waste disposal [4]. The construction industry, acknowledging the importance of environmental issues, has aim to find solutions that are able to combine economic aspects and growth and environmental conservation. Possible method should be the substitution of natural aggregates by recycled plastic aggregates in cementitious materials (mortars or concretes) [5]. From the literature, it appears, that incorporation of plastic waste as plastic aggregates in concrete leads into the significant improvement of thermal properties of developed composites [6, 7]. In that sense, this study is focused on the assessment of the lightweight concrete materials incorporating glass fiber reinforced polypropylene waste aggregates in terms of preferable thermal function and optimized energy performance in building construction.

2. Experimental research

Basic physical and thermal properties of GFPP aggregate were measured at first. Crushed waste glass fibre reinforced polypropylene (GFPP) used in this work was obtained from the PP tubes production Lightweight concrete was then prepared using silica sand, Portland cement CEM I 42.5 R, water and GFPP waste, which was used for the partial replacement of natural aggregate by 10, 20, 30, 40 and 50 mass %. The reference specimen without GFPP was prepared as well. The silica sand of fraction 0-2 mm was used. The water/cement ratio was 0.5 for all studied mixtures. The casted prismatic specimens (small beams) 40×40×160 mm and cubic specimens with side dimension of 70 mm were left for 1 day at laboratory conditions and then they were unmoulded and cured for 28 days in water until the tests. The mix proportions are summarized in Table 1.

Table 1: Composition of studied composites with GFPP waste

Mixture	Mass [g]				w/c
	Cement	Natural aggregate	Water	GFPP waste	
Ref	450	1 350	225	-	0.5
10 %	450	1 215	225	135	0.5
20 %	450	1 080	225	270	0.5
30 %	450	945	225	405	0.5
40 %	450	810	225	540	0.5
50 %	450	675	225	675	0.5

2.1. GFPP aggregate

In order to characterize GFPP, its powder (bulk) density, matrix density and grain-size distribution were determined. The average matrix density, measured using automatic helium pycnometer Pycnomatic ATC, was 940 kg/m^3. The grain-size distribution was analysed using standard sieve method with sieves of mesh dimensions 0.063- 63.0 mm. Obtained results showed that GFPP particles were smaller than 8 mm, what is beneficial for their incorporation into the composition of the lightweight concrete. The powder (bulk) density and thermal properties namely thermal conductivity λ (W/m·K), volumetric heat capacity Cv (J/m^3·K) and thermal diffusivity a (m^2/s) of GFPP aggregates were measured in dependence of compacting time, in order to get information on changes in thermal parameters based on aggregate processing. The compacting was done using a high-frequency vibrating table VSB-15. The highest compaction time corresponded to the steady-state specimen volume. To determine these thermal parameters, the commercially produced device ISOMET 2114 was used as a representative of transient impulse methods [8]. The measurement accuracy was 5% of reading + 0.001 W/m·K for the thermal conductivity in the range 0.015-0.70 W/m·K and 10% of reading for the thermal conductivity ranging from 0.70 W/m·K to 6.0 W/m·K. The accuracy of the measurement was 15% of reading + 1 × 10^3 J/m^3·K.

2.2. Thermal conductivity

In order to understand the influence of the plastic aggregate on improvement of thermal insulation properties of the developed lightweight composites, their thermal conductivity λ (W/m·K) was obtained using device ISOMET 2114. Measurement was performed in dependence on moisture content, from the fully water saturated state to dry state. Cubic lightweight concrete specimens were measured using surface probe (side with 70 mm).

2.3. Basic material properties

Not only basic material properties of the lightweight concrete specimens were examined. The bulk density, the matrix density and the total open porosity were determined. Composites were first dried in a vacuum drier at 60 °C. The matrix density was executed using automatic helium pycnometry as described above. The bulk density was given by gravimetric principle from measurement of specimen size and its dry mass according to EN 12390-7 [9]. On the basis of density measurement (bulk and matrix), the total open porosity value was calculated [10]. The relative expanded uncertainty of this applied measuring method was approx. 5 %.

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3. Results and discussion

Generally, the plastic waste aggregate had significantly better thermal parameters than silica sand typically used in concrete production [11].Thermophysical properties of GFPP aggregate together with corresponding powder density are summarized in Table 2. With compaction of concrete mixture, due to the elimination of air gaps between the plastic particles, all measured thermal properties have increased. Table 3. shows basic material and physical properties of tested lightweight concretes.

Table 2: GFPP aggregates thermal properties

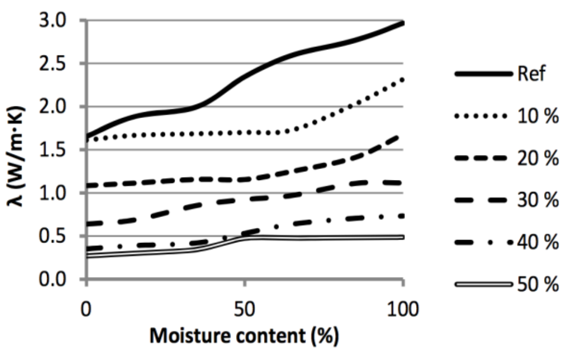
Compaction time [s]	Powder density [g/cm³]	λ [W/m·K]	$C_v \times 10^6$ [J/m³K]	$a \times 10^{-6}$ [m²/s]
0	0.394	0.092	0.266	0.347
30	0.468	0.098	0.314	0.311
90	0.487	0.099	0.323	0.307
240	0.490	0.100	0.325	0.312

Table 3: Basic physical properties of tested composites

Material	Bulk density [kg/m³]	Matrix density [kg/m³]	Open porosity [%]
Ref	2 064	2 508	17.7
10 %	1 852	2 225	16.8
20 %	1 611	2 003	19.6
30 %	1 319	1 821	27.6
40 %	1 053	1 652	36.3
50 %	895	1 589	43.6

The bulk densities of the shown mixtures with incorporated GFPP aggregates reached values in the range 800-1900 kg/m^3. Therefore, they can be classified as lightweight concretes in classes LC 1.0 - LC 2.0 and LC 2.1 respectively, according to the standard EN 206-1.

Material porosity of specimens with 10% incorporated GFPP was lower compared to the reference specimens; for 20, 30, 40 and 50% replacement of silica aggregate the total open porosity increased with the rate of substituted plastic aggregate. Such behaviour can be explained taking into account the un-porous structure of this plastic waste, which decreased the total open porosity of cement composites when be used in a lower amount, whereas the workability and thus air imbibition in the mixes was not negatively affected. On the other hand, the higher amount of plastic waste aggregates led to the increase in porosity due to the bigger particles and to the general coarsening of composites inner structure [2]. Packing density of granular mix can also increase the open porosity. The moisture dependent thermal conductivity of lightweight concrete is introduced in Fig. 1.



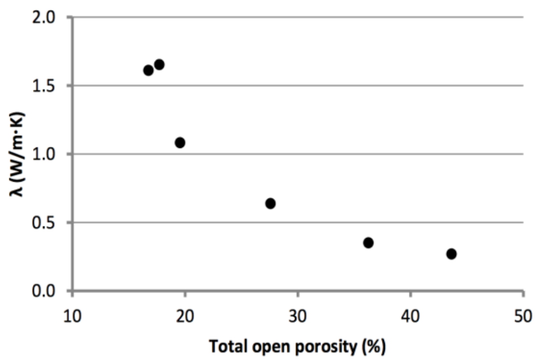


Figure 1. Thermal conductivity of lightweight concrete with GFPP in dependence on moisture content
Figure 2. Thermal conductivity of lightweight concrete with GFPP in dependence on the total open porosity (in the dry state)

The measured thermal conductivity has highly depended on moisture content. The effect of moisture content on the increase in thermal conductivity values was the highest for reference mix without GFPP use. In this case, the thermal conductivity has increased of about 74.4% for fully water saturated specimen compared to its dry value. It is quite logical, since GFPP granules were inert for water penetration and their inner encapsulated porosity contributed to the improvement of thermal conductivity without negative moisture effect. Regarding obtained data in Fig. 2, an exponential dependence of the thermal conductivity of researched composites in the dry state on their porosity should be see. The lowest contribution of moisture to the total thermal conductivity was observed for mix with 50 mass % of GFPP. Here, the difference between the dry and water saturated value of the thermal conductivity was about 38.1% only. The exception is the reference specimen, which at a higher porosity than composite with 10 % incorporated GFPP exhibited higher thermal conductivity. This is because the thermal conductivity in case of composites with plastic waste aggregates content does not affect only porosity, but also presence of plastic. Thermal conductivity is inversely related to the material weight.

4. Conclusions

Experimental research in the field of real application of the waste polypropylene in concrete was described in this paper. The assessment of thermal and basic material and physical properties of lightweight concrete with different amounts of glass fiber reinforced waste polypropylene was presented. The use of plastic particles (plastic aggregate) as sand substitution led to the increase in porosity and significant decrease in the bulk density. The results revealed the positive effect of GFPP aggregate incorporation on the moderation of heat transport even at presence of moisture. The use of plastic waste is an interesting way to extend its life in civil engineering applications providing lightweight concretes with enhanced thermal insulation properties. Because of environmental restrictions and rising costs of fuel end energy the energy performance of a building is becoming increasingly important nowadays. This is a way how to innovate view to design structures and safe environment.

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References

[1] Iucolano F., B. Liguori, B., Caputo, D., Colangelo, Cioffi, R., Recycled plastic aggregate in mortars composition: Effect on physical and mechanical properties. *Materials and Design*, 52, pp. 916-922, 2013.
[2] Z. Pavlík, M. Záleská, M. Pavlíková and R. Černý, “The thermal and mechanical performance of cement-based composites with enhanced thermal insulation properties”, in Heat Transfer XIII: Simulation and Experiments in Heat and Mass Transfer, edited by B. Sundén and C.A. Brebia (WIT Press, Southampton, 2014), 251-260.
[3] B. Coppola, L. Courard, F. Michel and L. Incarnato, Composites Part B 99, 75-83 (2016).
[4] PlasticsEurope, Plastics – the Facts 2015, www.plasticseurope.org, consulted January 2017.
[5] A. M. da Silva, J. de Brito and R. Veiga, Constr. Build. Mater. 71, 226-236 (2014).
[6] J. L. Ruiz-Herrero, D. V. Nieto, A. Lopéz-Gil and M. Rodríguez-Pérez, Constr. Build. Mater. 104, 298-310 (2016).
[7] R. Sharma and P.P. Bansal, Use of different forms of waste plastic in concrete – a review, Journal of Cleane Production, vol. 112,2016, pp 473-482.
[8] Z. Pavlík, M. Záleská, M. Pavlíková and R. Černý, “The thermal and mechanical performance of cement-based composites with enhanced thermal insulation properties”, in Heat Transfer XIII: Simulation and Experiments in Heat and Mass Transfer, edited by B. Sundén and C.A. Brebia (WIT Press, Southampton, 2014), 251-260.
[10] M. Keppert, P. Reiterman, Z. Pavlík, M. Pavlíková, M. Jerman and R. Černý, Cement Wapno Beton 15, 187-193 (2010).
[11] H. Kiyohashi, S. Sasaki, H. Masuda, High Temp.-High Press. 35/36, 179-192 (2003/2004)