IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Development of lightweight composites based on foam glass aggregate

To cite this article: J Zach *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **583** 012016

IOP Conf. Series: Materials Science and Engineering **583** (2019) 012016 doi:10.1088/1757-899X/583/1/012016

Development of lightweight composites based on foam glass aggregate

J Zach[1], M. Sedlmajer[1], J Bubenik[1], M Drdlova[2]

[1] Brno University of Technology, Faculty of Civil Engineering, Centre AdMaS, Purkyňova 139, 612 00 Brno, Czech Republic
[2] Research Institute for Building Materials, Hněvkovského 30/65, 617 00 Brno, Czech Republic

Email: zach.j@fce.vutbr.cz

Abstract. Building composites based on various types of lightweight aggregate have been widely used in the last decades for production of precast elements (e.g. panels) or whole structures with a good thermal insulation/mechanical properties ratio. The presented research investigated the feasibility of using foam glass aggregate, prepared from waste glass powder, in lightweight insulating composites for building industry. The effect of various binders (both organic and inorganic), binder/filler ratios and 3 types of fibres addition (PET, cellulose and mineral wool waste) on the physico-mechanical properties (bulk density, compressive strength) and thermal conductivity of the composite was evaluated. The results indicate, that applicable composites with sufficient mechanical parameters and low thermal conductivity (coefficient of thermal conductivity about 0,09 W/(m·K) can be prepared using both types of binders.

1. Introduction

Thermal protection of buildings (in the Czech Republic according to ČSN 730540) is currently one of the key requirements placed on building structures (in the Czech Republic according to Act 406/2000 Coll., as amended, and Decrees No. 268/2009 Coll. and 78/2013 Coll., as amended). The increasing demands on thermal protection of buildings respond to the global need to reduce CO_2 emissions and to reduction of consumption of non-renewable resources. Simultaneously, there is the pressure to improve the situation in the field of waste management and increase the share of waste recycling and the use of secondary raw materials in industry and construction.

Lightweight aggregate based on foam glass is a relatively new and environmentally friendly product that can be used alone in unbound applications or as a part of composite materials. This aggregate is made from waste glass powder, which is not suitable to be reused in the glass production, in terms of granulometry and chemical composition [1]. Glass powder can also be used directly in cement-based composites as an admixture. The final properties of foam glass aggregate depend on the production technology. Round grained aggregate is produced by packing and firing in a rotary kiln, sharp-edged aggregate is produced by the disintegration and crushing of larger foam glass plates produced continually in tunnel kilns. In both cases, different aggregate fractions are obtained (either directly, or subsequently by crushing and sorting) namely the broad or narrow aggregate fractions. This is very important for optimal design of composites, in particular of optimal design of granulometric curve [2].

IOP Conf. Series: Materials Science and Engineering **583** (2019) 012016 doi:10.1088/1757-899X/583/1/012016

The main advantage of the foam glass aggregate is its low bulk density, which varies (depending on the fraction) in the range of 90–430 kg/m^3, low thermal conductivity in the range of 0.06–0.11 W/(m.K) and high value of crush resistance (compression resistance) in the range of 0.3–2.0 N/mm^2.

2. Composites based on foam glass aggregates

Up to now, the foam glass aggregate was mainly investigated as partial substitute of natural aggregate in lightweight concrete. The properties at fresh and hardened state were evaluated, the results showed the potential for the use of foam glass aggregates in such concretes. [1] Foam glass aggregate can be also bonded to plates or shaped products by suitable binders. From the point of view of possible use in the building industry, composite materials based on foam glass can be used as insulating materials for applications with higher demands on the mechanical properties of the insulator. In this case, the insulator transmits a higher permanent load (e.g. roof and floor construction) or must withstand a higher random load in the structure (e.g. skirting board construction in thermal insulation systems, etc.). Such insulators are used primarily to eliminate or at least partially reduce thermal bridges [3]. Sometimes they can also be used in terms of positive acoustic properties (especially sound absorption) [4]. Studies regarding the utilization of foam glass aggregate in gap-graded type of composite with very low density intended to be used in thermal insulating applications are scarce. The presented research investigates this posibility with emphasis on evaluation of the effect of various binders, binder/filler ratios and fibre addition on the physico-mechanical properties and thermal conductivity of the proposed composite.

3. Materials and methods

Sharp-edged lightweight aggregate (fractions 4/16 and 16/32 mm) from crushed foam glass was chosen for experimental works. This aggregate is produced by Refaglass company from waste packaging glass, which is not suitable to be reused in glass industry. Cement 42.5 R Mokra was used as an inorganic binder, the polyurethane resin Leeson D3149/20 and polyester resin Havelpol 2 were used as organic binders. The amount of binder was designed as to achieve the optimum ratio of mechanical parameters and thermal insulation properties. In the case of cement-based composites, only the aggregate of fraction 4/16 was used and the cement dose was uniformly chosen to be 100 kg per 1 m^3 (based on the results of previous research [2]). In order to improve the properties (primarily mechanical) of the composite, recycled fibres based on cellulose, garnetted mineral wool and garnetted PET bottles were added, each at 5% of the weight of the cement. A total of 4 formulae were designed that differed in the used fibre type (one formula was reference without fibres). The difference was still in the amount of water due to the different type of fiber, the design was made for the same consistency. A superplasticizer was used to reduce the water-cement ratio. The individual formulae used are described in table 1.

Table 1. Composition of individual formulae of lightweight concrete with open structure.

Entry component			Recipe 1 m^3			
			CEM 1	CEM 2	CEM 3	CEM 4
Cement CEM I 42.5 R Mokrá		[kg]	100	100	100	100
Aggregate 4–16 mm REFAGLASS		[l]	1000	1000	1000	1000
Water		[l]	67	88	82	61
Plasticizing admixture MURAPLAST FK 19		0.8% m_c [kg]	0.80	0.80	0.80	0.80
Fibers	PET	5% from m_c [kg]	-	-	5	-
	cellulose		-	5	-	-
	Mineral wool		5	-	-	-
Water cement ratio		[-]	0.67	0.88	0.82	0.61

In the case of polymer binder composites, both fractions 4/16 and 16/32 were used with two binder doses, 25 and 30 wt. %. Those doses were selected based on the previous research as to achieve uniform coating of the aggregate grains at the lowest possible binder amount. The excessive amount of binder increases production costs and also reduces the thermal insulation properties of the resulting composite. A total of 4 formulae were designed, which are listed in table 2.

Table 2. Composition of optimized samples with polymer binder.

Sample identification/component	Binder	Binder weight ratio [%]
PU 16/32	Polyurethane	25
PU 4/16	Polyurethane	30
PES 16/32	Polyester	25
PES 4/16	Polyester	30

Based on the above-mentioned formulae, 150 mm cube-shaped samples (see example in figure 1) were prepared from both types of composites to determine physico-mechanical properties, as well as 300 x 300 x 50 mm plate-shaped samples to determine thermal insulation properties. The mixtures were placed into the moulds treated with the releasing agent and compacted with light 1kN pressure and vibration. Determination of following properties was carried out:

1. Density in fresh/hardened state (EN 12350-6, ČSN EN 12390-7), [9, 10]
2. Compressive strength (EN 12390-3), [11]
3. Thermal insulation properties (EN 12667, ISO 8301). [6, 7]

Figure 1. Example of composite samples with polymer binder.

4. Measurement results

Physico-mechanical and thermal insulation properties were determined on the test samples of both types of composite materials. The results of the determination of physico-mechanical properties (average values of at least 5 test samples) are given in tables 3 and 4:

Table 3. Physico-mechanical properties of cement-based samples.

Sample identification /parameter	Bulk density [kg/m^3]	Compressive strength [MPa]
CEM 1	490	1.10
CEM 2	490	0.69
CEM 3	500	0.78
CEM 4	530	1.48

Table 4. Physico-mechanical properties of polymer-based samples.

Sample identification /parameter	Bulk density [kg/m^3]	Compressive strength [MPa]
PU 16/32	324	0.67
PU 4/16	363	0.65
PES 16/32	306	0.28
PES 4/16	365	0.41

As can be seen from the values given in tables 3 and 4, the composites based on cement binder showed better mechanical properties and higher bulk density than the organic polymer binder composites. Comparing the PU and PES resin binders, better mechanical properties were achieved in case of PU binder, the compressive strength was about twice higher. This is partly connected with the mechanical properties of the PU resin itself (higher toughness and flexural strength compared to PES resin), but can be also attributed to higher viscosity of PU resin, which is more suitable for bonding the absorptive foam glass aggregate from the technological point of view. The porous aggregate tends to absorb low viscosity PES resin extensively, which reduces the amount of resin for binding and thus final strength of the composite.

In compliance with expectations, the compressive strength raises with increasing amount of binders in both cases.

Regarding the specimens bonded with cement-based matrix, it was observed, that addition of any waste fibres does not improve compressive strength of the composite. Presumed reason is overall low amount of cement matrix and the gap-graded structure of the whole composite, in which the fibres cannot be strongly anchored and evenly dispersed to bring proper load bearing capacity.

Determination of thermal insulation properties of samples in dried state was performed. The thermal conductivity was determined as $\lambda_{10,dry}$ [W/(m.K)]. The results are shown in tables 5 and 6.

Table 5. Thermal technical properties of cement-based samples.

Sample identification /parameter	Bulk density [kg/m^3]	Coefficient of thermal conductivity [W/(m·K]
CEM 1	420	0.1036
CEM 2	430	0.0975
CEM 3	450	0.1002
CEM 4	430	0.1019

Table 6. Thermal technical properties of polymer-based samples.

Sample identification /parameter	Bulk density [kg/m^3]	Coefficient of thermal conductivity [W/(m·K)]
PU 16/32	324	0.0927
PU 4/16	363	0.0913
PES 16/32	306	0.0877
PES 4/16	365	0.0867

As can be seen from the results, the samples bonded with organic binder show slightly lower thermal conductivity, which is given both by the organic binder with lower thermal conductivity than cement and also by the lower density of the samples. It is also apparent that samples with a 4/16 aggregate fraction with a higher density compared to samples with 16/32 fraction showed better results of thermal insulation properties. This is due to the structure of the air pores and their thermal properties in the individual types of composite. The 4/16 fraction composite contains smaller air pores and cavities compared to the 16/32 fraction, which is beneficial for the final insulating properties of the composite. In the case of cement bonded composites, relatively small differences in thermal conductivity have been found among investigated mixes. The best values were found for formula no. 2 with cellulose based fibres, but the difference can be considered as insignificant. Addition of any tested fibre into the designed gap graded composite does not affect the thermal insulating properties.

In general, it can be stated that both types of composites exhibited comparable mechanical properties at a given density, as did lightweight concretes described in scientific papers [1, 3]. Regarding the observed dependencies of thermal conductivity coefficient to density, the results correspond to the conclusions of other scientific papers dealing with similar issue of lightweight composites with comparable density and porosity [5].

5. Conclusion

The objective of the presented research was to develop gap-grading composite with the optimal ratio of thermal insulating and mechanical properties and to evaluate the effect of various binders (both organic and inorganic), binder/filler ratios and 3 types of fibres addition (PET, cellulose and mineral wool waste) on the physico-mechanical properties (bulk density, compressive strength) and thermal conductivity of the composite.

The following conclusions can be drawn:

- The usage of the foam glass aggregate in gap-grading composites for thermal insulation applications in building industry is feasible with both cement and organic resin binders. All prepared specimens showed low thermal conductivity (around 0.09 W/(m.K)) and sufficient mechanical parameters to be implemented in applications with higher demands on the mechanical properties, such as skirting board construction in thermal insulation systems, etc.
- Samples bonded with organic binder show slightly lower thermal conductivity, which is given both by the organic binder with lower thermal conductivity (compared to cement) and also by the lower density of the samples.
- Samples with a 4/16 aggregate fraction with a higher density compared to 16/32 fraction showed lower thermal conductivity, which is mainly attributed to the structure of the air pores of the 4/16 aggregate and the whole composite.
- The addition of waste fibres does not positively affect the mechanical properties of the composite and the influence of the fibres presence on the thermal conductivity is minimal. On the other hand, the fibres positively influenced compactness and homogeneity of samples.

Acknowledgements
This paper was written under the project No. LO1408 “AdMaS UP - Advanced Materials, Structures and Technologies”, supported by the Ministry of Education, Youth and Sports under the “National Sustainability Programme I” and project FV20086 "Development of light new-age building materials with utilization of light-weight aggregate based on waste glass powder" supported by the Ministry of Industry and Trade.

References
[1] Limbachiya M, Meddah M S and Fotiadou S 2012 Performance of granulated foam glass concrete *Construction and Building Materials* **28** pp 759–768
[2] Zach J, Sedlmajer M, Novák V and Bubeník J 2018 Utilization of lightweight aggregate based on foam glass in lightweight concrete with extremely low density *In 20. Internationale Baustofftagung - IBAUSIL 2018* **1** pp 295–301
[3] Real S, Gomes M G, Rodrigues A M and Bogas J A 2016 Contribution of structural lightweight aggregate concrete to the reduction of thermal bridging effect in buildings *Construction and Building Materials* **121** pp 460–470
[4] Park S B, Seo D S and Lee J 2005 Studies on the sound absorption characteristics of porous concrete based on the content of recycled aggregate and target void ratio *Cement and Concrete Research* vol 35 issue 9 pp 1846–1854 (doi:10.1016/j.cemconres.2004.12.009)
[5] She W, Zhang Y and Jones M R 2014 Three-dimensional numerical modeling and simulation of the thermal properties of foamed concrete *Construction and Building Materials* **50** pp 421–431
[6] ISO 8301:1991 *Thermal insulation - Determination of steady-state thermal resistance and related properties - Heat flow meter apparatus*
[7] EN 12667:2001 *Thermal performance of building materials and products. Determination of thermal resistance by means of guarded hot plate and heat flow meter methods. Products of high and medium thermal resistance* (Geneva, Switzerland: STANDARD by International Organization for Standardization)
[8] EN 12350-2:2009 *Testing fresh concrete - Part 2: Slump-test*
[9] EN 12350-6:2009 *Testing fresh concrete - Part 6: Density*
[10] EN 12390-7:2009 *Testing hardened concrete - Part 7: Density of hardened concrete*
[11] EN 12390-3:2009 *Testing hardened concrete - Part 3: Compressive strength of test specimens*