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Development of Light-Weight Fibre-Based Materials for Building Envelopes

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Abstract**—**Thin-walled elements with a matrix set on a base of high-valuable Portland cement with dispersed reinforcement from alkali-resistant glass fibres are used in a range of applications as claddings of buildings and infrastructure constructions as well as various architectural elements of residential buildings.

Even though their elementary thickness and therefore total weight is quite low, architects and building companies demand on even further decreasing of the bulk density of these fibre-cement elements for the reason of loading elimination of connected superstructures and easier assembling in demand conditions.

By the means of various kinds of light-weight aggregates it is possible to achieve light-weighing of these composite elements.

From the range of possible fillers with different material properties granulated expanded glass worked the best.

By the means of laboratory testing an effect of two fillers based on expanded glass on the fibre reinforced cement composite was verified.

Practical applicability was tested in the production of commonly manufactured glass fibre reinforced concrete elements, such as channels for electrical cable deposition, products for urban equipment and especially various cladding elements.

Even though these are not structural elements, it is necessary to evaluate also strength characteristics and resistance to environment for their durability in certain applications.

Keywords**—**Fibre-cement composite, granulated expanded glass, light-weighing.

I. Introduction

FINE-GRAINED cement composite with dispersed fibre-reinforcement is used for the production of large-sized elements, such as aerated facades, thermally insulated facades, architectural facade elements, shaped architectural elements, balcony panelboards, installation channels, light-weight walls or sound protection walls.

The aim of our project was to decrease the total weight of selected building products with the result in reduction of demands in production and installation. The light-weighing should be achieved by the means of lower bulk density with the same dimensions of used products. Required bulk density corresponds with light-weighing ca. 25%, i.e. a value of 1,600 kg/m^3.

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II. Light-Weighing Possibilities of Cement Composites

By the means of various kinds of light-weight aggregates [1] or air-entraining agents it is possible to achieve light-weighing of thin-walled fibre-cement composite elements.

The advantage will be decreasing of production, transport and assembly costs and reduction of heavy machinery.

In one part of our research light-weighing possibilities of standard composition were evaluated by the means of porous structure creation. In the second part the standard aggregate was substituted with available kinds of light-weight porous aggregates in a certain part or in a whole volume (e.g. polymer expanded spheres, glass hollow spheres, granulated expanded glass).

Several compositions were designed by the means of a standard mixture modification and substitution of commonly used fine-grained silica sand. Decreasing of bulk density of the final cement composite was realized, when filler with distinctive lower density compared to sand was used.

At first available various light fillers were tested and their influence on production technology and final properties of the composite was evaluated.

Several types of filler in different fractions were used in a way to substitute 50 to 100% vol. of silica sand in the initial matrix according to their bulk density [2].

The final results of specimens with most appropriate fillers are stated in Table I.

III. Granulated Expanded Glass

In the second stage of our research possibilities of light-weighing were evaluated for substitution 50-100% vol. of sand by the means of using granulated expanded glass in fractions 0.25-0.5, 0.5-1 and 1-2 mm. Glass fibre reinforcement was used in amounts 2.0, 2.5 or 3.0% wt. of total dry mixture.

According to our expectations the decrease in bulk density was in correlation with the amount of the used filler. 50% sand substitution reached bulk density value only 1,800 kg/m^3, but 75% substitution caused light-weighing to the level of 1,600 kg/m^3. And the total substitution of 100% enabled the decrease in bulk density even to 1,500 kg/m^3.

Flexural strength was in the interval 9-14 MPa; the higher amount of expanded glass and the lower amount of glass fibres the lower values of the flexural strength were achieved. The range of results was evaluated 4.5-6.5 kJ/m^2 for the impact resistance and 10-15% for the absorptivity.

We can conclude that Liaver seems to be the suitable filler for the required bulk density achievement.

TABLE I
PROPERTIES OF THE CEMENT COMPOSITES WITH LIGHT-WEIGHING FILLERS

Filler	Substitution for sand [vol.%]	Bulk density [kg/m^3]	Flexural strength [MPa]	Absorptivity [%]	Impact resistance [kJ/m^2]
expanded polymer microspheres 15- 25 μm	3.5[1]	1,434	7.57	15.13	7.32
expanded volcanic glass 0-1 mm	100	1,726	13.95	14.65	7.43
granulated expanded clay 0-2 mm	75	1,650	10.75	12.92	5.09
granulated expanded silica sand 0.6-2.5 mm	100	1,694	6.42	15.73	5.97
exfoliated vermiculite 0.25-0.71 mm	100	1,501	11.12	16.98	6.00
granulated expanded glass 0.25-0.5 mm	85	1,545	10.31	13.76	5.68

[1]Expanded polymer microspheres were added in the amount of 3.5% wt. from the total sand weight without its substitution

TABLE II
COMPARISON OF FILLERS FROM EXPANDED GLASS

Filler	Fraction [mm]	Loose density [kg/m^3]	Bulk density [kg/m^3]	Grain strength [MPa]
expanded glass Liaver	0.25-0.5	300	540	3.4
	0.5-1	250	450	3.3
	1-2	220	350	3.0
expanded glass Poraver	0.25-0.5	340	700	2.6

TABLE III
COMPARISON OF THE CEMENT COMPOSITES WITH FILLERS FROM EXPANDED GLASS

Filler	Sand substitution [%]	Bulk density [kg/m^3]	Flexural strength [MPa]	Absorptivity [%]	Impact resistance [kJ/m^2]
expanded glass Liaver 0.25-0.5 mm	85	1,545	10.31	13.76	5.68
	100	1,478	9.69	14.22	5.41
expanded glass Poraver 0.25-0.5 mm	85	1,656	12.15	14.04	6.50
	100	1,571	12.37	14.06	7.36

A. Comparison of Expanded Glass Fillers

Following the successful results with granulated expanded glass Liaver, the same tests for alternative filler Poraver on the same basis with slightly different properties were conducted. Examples of filler appearances are shown in Figs. 1 and 2. The basic characteristics of both fillers from expanded glass are stated in Table II [3], [4].

Comparing the fillers with same fraction 0.25-0.5 mm Poraver has ca. 50% higher price than Liaver.

The set of specimens was prepared in a laboratory to compare basic properties of the cement composites with decreased bulk density by fillers Liaver and Poraver with the same fraction 0.25-0.5 mm.

As stated in Table III we can conclude that compared to Liaver the specimens with Poraver of the same volume content have higher bulk density, on the contrary flexural strength and impact resistance were higher and absorptivity was equal in both cases. Workability was not affected in the case of the alternative filler. For the complex evaluation the higher price of Poraver should be taken into account.

B. Evaluation in Real Production

For this evaluation a mixture consisting of 3 fractions of Liaver was used. The final fraction was counted as a weight ratio 33:33:33 of individual fractions 0.25-0.5, 0.5-1 and 1-2 mm.

Fig. 1 Granulated expanded glass Liaver

Fig. 2 Granulated expanded glass Poraver

TABLE IV
COMPARISON OF PRODUCTS LIGHTENED BY LIAVER

Product	Property	Standard	Liaver I	Liaver II
cable channel	weight [kg]	20.0	16.3	15.2
	flexural bearing capacity [kN]	3.0	1.3	2.2
bulk flower pot	weight [kg]	110.0	87.5	84.8

TABLE V
MAXIMAL LOADING AND STRAIN IN CROSS SECTION OF INDIVIDUAL ELEMENTS

Element No.	Composition	Maximal loading p_u [kN/m^2]	Maximal strain σ_u [MPa]
T1	standard	10.45	11.48
T2	expanded glass Liaver I	7.55	10.20
T3	expanded glass Liaver II	13.45	17.19

Two compositions were designed with different sand substitutions and glass fibre additions. The first mixture marked as Liaver I consisted of granulated expanded glass in 75% substitution and 3.5% fibre content. The second mixture marked as Liaver II consisted of granulated expanded glass in 80% substitution and the fibre content was decreased to 2.5% for better workability and fluidity achievement [2].

For homogenization a mixer with rotating central paddle was used in the same way as for the standard production.

Besides the comparison of the final weight of products a flexural bearing capacity of cable channels was carried out in accordance with the company standard PN-VUSTAH 0211:2006. The channel equipped with a lid in the upward position was submitted to continual loading 75 N/s, the support distance was 1,800 mm and fracture force was measured in the middle of this distance.

A decrease of weight was achieved with composition Liaver I up to 20% and Liaver II up to 25% (see Table IV). In the same way we can observe a decrease in flexural bearing capacity. The optimization process should be conducted afterwards.

C. Durability Testing of Bridge Cladding Elements Exposed to Wind Loading

The same mixture with the expanded glass filler Liaver was adapted for a spraying technology and several cladding elements were made for further testing as shown in Fig. 3.

This technology has been successfully verified in the production of manufacturing and assembling company DAKO Brno, Ltd. An example of realization of these elements is shown in Fig. 4.

Perspective bridge cladding elements were examined in the laboratory of Brno University of Technology concerning their durability within wind loading [5].

Tested elements were fixed in the same way as standard cladding elements to simulate real conditions. One part of each element was fixed to steel profiles, whereas the other part was not supported. The second part in real construction serves for covering of installation cables and pipelines. This part works as an overhanging end or rather a cantilever under uniform loading.

Fig. 3 Spraying of bridge cladding element

Effect of uniform loading caused by wind is simulated by the means of vacuum creation. Each element was fixed in a solid box and covered with a transparent plastic foil. Air was sucked out of this space and induced atmospheric pressure has the same effect on the tested element as real uniform loading caused by wind. The setting of the durability test is shown in Fig. 5.

Two cladding elements lightened with the expanded glass filler were compared to standard cladding elements with positive results, which are stated in Table V.

According to our experiments we can conclude, that after optimization process of light-weight fibre-cement composites we can meet better technological properties of these products.

Material costs are expected to be higher, but this disadvantage will be compensated with decreasing of production, transport and assembly costs.

Fig. 4 Bridge cladding elements assembled at the foot bridge across a river

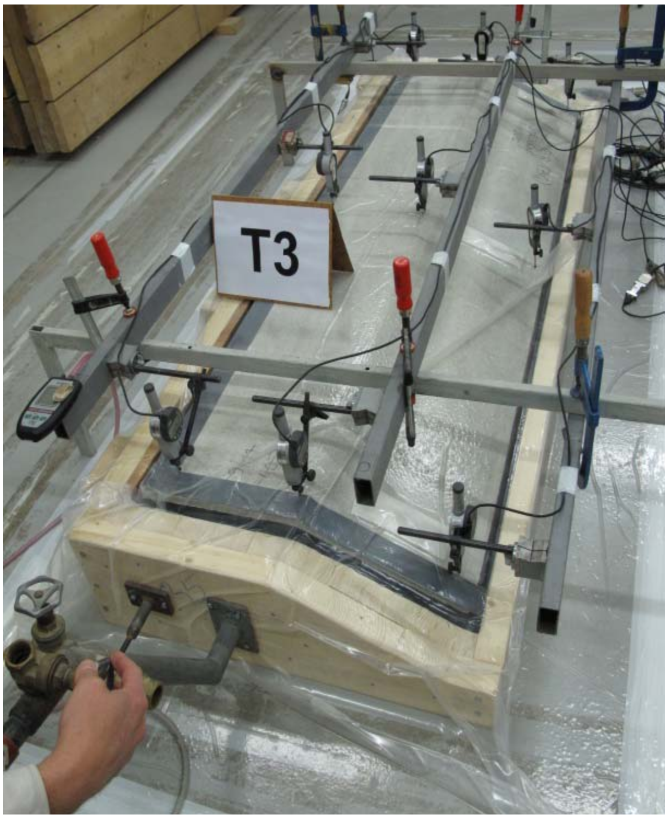

Fig. 5 Setting of durability tests

IV. Conclusion

- The most appropriate filler for light-weighing of thin-walled fibre-cement elements was the granulated expanded glass Liaver, which can ensure acceptable final properties.
- By the means of this light-weight filler it is possible to decrease bulk density of the fibre-cement composites up to 25%.
- The fibre-cement composite with bulk density 1,600 kg/m^3 can be therefore reached, as it was confirmed in the real production conditions.
- Reduction of transport costs for light-weight elements was calculated ca. 18%
- Reduction of assembly costs was calculated ca. 25%.
- Reduction of material costs for a distinctive lighter superstructure was calculated ca. 15%.

Acknowledgment

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