Composite modifications obtained through various technological approaches based on inorganic binders and foam glass materials

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Abstract: *Composite structural modifications based on hydraulic inorganic binders and foam glass aggregate fractions were prepared. Formwork moulds were developed for the moulding of composite test bodies using different technological approaches. A series of experimental specimens meeting the requirements for standard laboratory tests were obtained. The role of the technological regimes used in the formation of the structural characteristics and performance of the composites is examined. The existing possibilities for further modification and potential application of the obtained composite materials are analysed.*

Keywords: *COMPOSITE MODIFICATIONS, FORMWORK MOULDS, INORGANIC BINDERS*

1. Introduction

The intensive expansion of large urbanized territories is accompanied by the active construction and reconstruction of a diverse building stock, the establishment of industrial zones and the development of transport infrastructure. In this aspect, the quality of the construction and renovation activities carried out is dependent on the technological and operational characteristics of the building materials used [1-3]. At the same time, the modern development of construction is today associated with the active application of innovative materials that meet the requirements for energy efficiency and adequate noise insulation of buildings [3-5].

On the other hand, the growing quantities of waste products (of industrial, construction and household nature) create conditions for the emergence of environmental and other accompanying problems in their collection and disposal. A main approach to reducing the negative impact of these factors on the state of the environment is the implementation of complex strategies for long-term waste management and recovery [6, 7]. Greater deployment of appropriate green technologies, providing for the efficient recycling of a variety of waste materials with a view to their use as raw materials, is essential for a sustainable improvement of environmental security [8-10]. Cost-effective production technologies have been developed for the production of separate categories of foam silicate materials by utilizing significant amounts of waste glass (of various origins) [11-13]. One basic technological approach is the thermal foaming of powder fractions of waste glass (obtained after grinding) in the presence of suitable foaming additives [11, 12]. The development allows for the recycling of waste materials that are practically non-degradable in the natural environment. For the realization of the production process, systems of specialised equipment, applicable in conjunction with standard equipment, have been developed [11]. Foam glass materials are used in the construction for thermal insulation of buildings (of various types), installations and equipment [14].

Composite materials involving inorganic binders and granular foam glass have been developed [15-19]. The resulting composite materials combine the specific characteristics of the components used and are suitable for the preparation of non-load-bearing, non-combustible, water-resistant, long-lasting thermal and acoustic insulation panels, boards, profiles etc [15-18]. A promising opportunity for further functional development of the developed composites is their structural modification by using different technological approaches. In relation to this, a preliminary study across a wide thematic range has been carried out [20-34].

The experimental research work carried out led to the conclusion that the existing traditional laboratory formwork moulds (of different materials) are inappropriate for forming test bodies when using some of currently employed technological approaches. Therefore, there arose a methodological need to apply formwork moulds meeting the requirements of the developed composite materials.

The aim of the present work is to present the main design characteristics and application possibilities of innovative formwork moulds, tailored to the specificity of the technological methods used for the preparation of composite experimental specimens based on inorganic binders. Composite modifications obtained in laboratory conditions by using different technological modes are considered. The main structural characteristics of the obtained materials and the prospects for their potential application are analyzed.

2. Materials and methods

The development uses various raw materials, components, technological additives and standard equipment: laboratory balances Kern type ABJ220-4NM, platform balances with a weighing capacity of up to 10 kg, a ball mill with a working volume of 50 L (at a working speed of approx. 260 rpm), agate mortar, a set of sieves, laboratory baths, a perforated spatula, a grid stand, a granulator, programmable muffle furnace LM-312.11, waste glass (origin - municipal waste), foaming additive (glycerine or calcium carbonate), sodium silicate (module 3.0), Portland cement (CEM I 52.5 R, white CEM I 52.5 N or CEM I 42.5 N), gypsum, technical silicone, etc. Perlite (mainly in a fraction of up to about 3 mm), reinforcing fibres, etc. were used as additional components for some of the formulations. The quantities of waste glass provided were subjected to a two-stage grinding process (from initial coarse crushing to obtain powder fractions).

In accordance with the basic requirements for performing various standard laboratory tests of construction materials, sets of formwork moulds were developed for the preparation of composite test bodies:
- cubes with dimensions 100x100x100 mm for compressive strength testing;
- prisms with dimensions 100x100x400 mm for flexural tensile strength testing;
- plates with dimensions 250x250x50 mm for studying the thermal conductivity coefficient.

The technological process for the preparation of the designed formwork moulds involves preparing a model and a gypsum mould with silicone inserts.

The obtained formwork moulds consist of two gypsum side parts with silicone inserts and a bottom part (fig. 1 and 2) with an additional silicone element (overlay or insert). This allows for the application of different technological schemes for moulding composite structure specimens. The silicone inserts of the side parts end on both sides with tensioning elements that fix them to the gypsum parts so as to prevent their deformation when in use. In the molding process, the silicone inserts form the sides of the test bodies, while the bottom forms their lower part.

The design of the bottom of the main formwork moulds includes a drainage system as a structural element which allows the separation of part of the liquid phase (from the introduced mixture consisting of cement mortar and foamed silicate aggregates). Separate sets of formwork moulds have been developed: with a bottom of solid gypsum with perforated holes (and an additional silicone overlay) or with special bottom made of a modified silicone insert with an integrated sieve (or grid element) and silicone overlay. The incorporated sieve is made of corrosion-resistant material with a mesh size smaller than the minimum grain size of the fractions of lightweight additive materials used. The insertion of the silicone overlay upon the bottom blocks the outlet holes and prevents the liquid phase leaking out. At the same time, additional formwork moulds with a monolithic gypsum bottom (without perforations) and a silicone insert were developed as well.

Fig. 1. *Formwork mould for the preparation of composite specimens.*

Fig. 2. *Formwork mould for the preparation of composite specimens.*

A series of composite specimens involving lightweight silicate aggregates and hydraulic binders were prepared in laboratory conditions.

Fractions of foamed glass granules were obtained by applying controlled thermal foaming (at temperatures of up to 900°C) to a primary granulate prepared from a powder fraction of waste glass, a foaming additive and a plasticizer.

Cement mortars (with different values of w/c ratio) were prepared, to which foam-silicate aggregates and additional components were introduced. The complete wetting of the foam-glass aggregates in the cementitious solutions is considered as a recommended technological condition. This allows individual surface pores to close and ensures the presence of a surface layer of binder in the contact areas of adjacent aggregates. After intensive homogenisation, the resulting mixtures were distributed by pouring them into the prepared formwork moulds.

The design features of the formwork moulds allow, by using different technological approaches, to obtain composite specimens with different structures.

Regardless of the compositions and technological methodology used, all specimens were subjected to a residence time (in the formwork moulds) of up to 48 h, after which they were carefully removed from the formwork moulds.

The main differences between the individual composite modifications obtained by the different technological approaches consist in the varying specificity of the structure thus formed and the amount of residual cement phase in the final specimens.

3. Results and discussion

From the prepared mixtures (cement mortar and granules), experimental specimens were moulded by controlled drainage of a portion of the liquid phase through the perforated holes or the embedded sieve at the bottom of the formwork moulds. The implementation of this technological process involves mounting the formwork moulds on metal stands, under which are placed laboratory vats provided for the collection of the draining liquid phase. The application of a water cement w/c ratio in the range of 0.6 to about 0.9 enables the full use of the existing technological capabilities of the methodology and obtaining materials with relatively low mass.

Placing the silicone overlay stops liquid phase drainage at a predetermined technological stage and allows influencing effectively the formation of the structural specificity of the obtained final samples. The method provides adequate control of the available cement mortar and of the bulk density and mass values of the resulting specimens.

Due to the reduced presence of binder, the final specimens thus prepared are characterized by relatively lower mechanical properties. This effect can be partially limited through the use of higher strength cements (CEM I 52.5 R or others), the introduction of suitable plasticising additives, modifiers, etc. For some product categories for which there are no regulatory requirements for increased mechanical properties, this composite structure allows to obtain various modifications tailored to a specific functional role.

The use of different fractions of foam-silicate aggregates with an appropriate ratio of the radii of the individual granules allows obtaining materials with a variety of structures (fig. 3).

Fig. 3. *Structure of an experimental specimen (fragment).*

Due to the gradual drainage of a significant part of the cement solution, the prepared specimens have as a characteristic structural feature the availability of direct contact between individual aggregates and the formation of interconnected gaps between adjacent granules. Composite modifications with relatively uniformly sized interconnected gaps allow for the preparation of drainage elements potentially applicable in different operating conditions.

In the experimental specimens prepared with the use of only larger fractions of foamed glass aggregates, a structure with distinct and relatively large interconnected free gaps was observed.

A promising option for additional modification of the obtained composite materials is their further technological processing by impregnation with mixtures of inorganic binders solutions of and non-combustible thermal insulation fillers (perlite or others).

On the basis of two aggregates fractions with a suitable radii ratio, it is possible to form a relatively compact composite structure in which the introduced smaller aggregates are positioned in the free spaces between the granules of the larger fraction. At the same time, the foam glass granules obtained in real technological conditions are characterized by a variety of individual shapes, in a number of cases different from an ideal sphere. Therefore, the software-generated three-dimensional models of composite systems built on the basis of aggregates with ideal spherical shape provide only an approximate idealized view of the state of the structure and the possibilities for optimising the materials.

Developed in addition to the technological approach considered here is an alternative version which provides for an initial distribution in the form of a layer of the prepared mixture (cement mortar-foam granules) placed on a separate grid stand. This allows for a more efficient drainage of a significant part of the liquid phase. After a process time of 5 to 10 min, the resulting residual mixture is introduced into the formwork moulds.

A comparative series of composite test specimens was prepared without draining the liquid phase (following the classical method). The specimens were made using formwork moulds with a silicone overlay pre-placed on the bottom (prior to the introduction of the prepared cement mortar-silicate aggregate mixture), which prevent free drainage of the liquid phase. Another technological option is the use of formwork moulds with a monolithic bottom (without perforation) and a silicone insert.

The molded compact specimens are characterized by a typical composite structure formed by the cement phase (acting as a matrix) and fractions of glassy aggregates distributed in the volume of the material. The resulting composites represent a potential fully functional alternative to different types of standard thermal insulating lightweight concretes obtained with the participation of conventional lightweight aggregates.

This technological method enables the preparation of relatively more massive composite samples with increased mechanical characteristics, but at the same time with higher values of bulk density and relatively higher mass of the material. Observation of the prepared cross-sections of the moulded experimental specimens revealed mainly extensive zones with a predominant concentration of foam silicate aggregates (fig. 4).

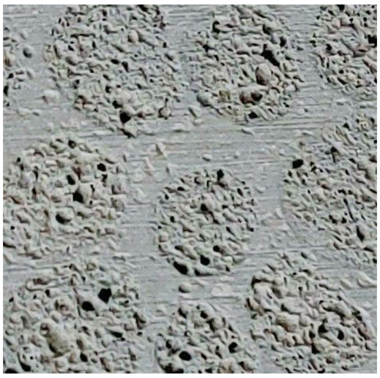

Fig. 4. *Section (fragment) of experimental composite specimens.*

At the same time, the cross-sections of some of the obtained composites showed the presence of limited local areas composed predominantly of massive cement phase. The considered technological method is suitable for moulding composite specimens mainly at w/c ratio of about 0.5 or lower values.

An appropriate technological option for the preparation of other composite modifications is the initial co-introduction (in the prepared cement mortar) of the necessary fractions of granulated foam glass and of other additional components (expanded perlite and/or reinforcing fibres, etc.).

The performance characteristics of the base components used in the development (Portland cement and foam-silicate aggregates) ensure the production of durable, waterproof and non-combustible materials.

The main technological guidelines for the optimization of the structure and functional capabilities of composites is the use of appropriate fractions of lightweight additive materials, the application of appropriate proportions between the amounts of cement mass and foam silicate aggregates, the use of more prolonged and intensive homogenization of the prepared mixture (cement mortar - granules), etc.

4. Conclusions

Formwork moulds kits were developed to mould experimental specimens with composite structure based on inorganic hydraulic binders and foam glass aggregates. The design characteristics of the formwork moulds allow for the application of different technological approaches in the moulding process: by controlled drainage of part of the cement mortar or without removal of part of the liquid phase. The specimens thus prepared can be used for laboratory tests to determine compressive strength, flexural tensile strength and to study the thermal conductivity coefficient.

The specificity of the used compositions and the capabilities of the individual technological schemes offer a possibility to obtain a variety of composite modifications. A comparative analysis of the specimens prepared under different technological regimes has revealed characteristic structural differences and variations of the amount of cement phase, all of which determine the performance properties of the composites and the potential opportunities for their functional application.

A possible alternative use of the prepared formwork moulds lies in the moulding of experimental specimens obtained from other materials, subject to the necessary technological and methodological compatibility.

5. References

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