Production technology and properties of polystyrene concrete on recycled polystyrene

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Abstract. The article deals with the production of polystyrene concrete from recycled polystyrene crushed in a rotary crusher waste from the production of foam packaging. The resulting polystyrene concrete can be attributed to thermal insulation, used for insulation of load-bearing structures of buildings, as well as to structural and thermal insulation, used as a bearing layer of the outer walls of low-rise buildings. The dependence of the thermal conductivity of the sample on the density and strength of polystyrene concrete has been established, and the resistance to shock loads depends not only on the composition but also on the polystyrene concrete hardening accelerator used.

1 Introduction

High-quality thermal protection of buildings, contributing to energy and resource conservation, is one of the most important tasks of modern construction. Reducing the material consumption of buildings, in turn, reduces the load on load-bearing structures and reduces construction costs. Such materials include polystyrene concrete [1-3].

Polystyrene concrete is a representative of lightweight concrete with expanded polystyrene filler. It is produced using a porous filler of low grain strength. Therefore, the decisive factor in the design of its properties is the structure of the hardened cement matrix, and the filler particles affect the mass of the resulting material.

The use of expanded polystyrene pellets from packaging material or waste from its production opens up new aspects of cost reduction and expansion of polystyrene concrete production volumes.

The technological line for the production of polystyrene concrete, which involves the use of crushed polystyrene granules obtained from foams, is not much different from the production of foam or aerated concrete [4].

As a binder component of polystyrene concrete, Portland cement and its varieties can be used [5], finely ground or highly dispersed wastes of the chemical, metallurgical, and energy industries sealed with alkaline components [6, 7], construction gypsum [8], etc.

Due to the use of crushed polystyrene granules obtained from foams, the cost price is reduced, environmental safety is ensured and the formation of waste from foams in garbage dumps is eliminated.

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To increase the density and strength, as well as other characteristics of polystyrene concrete, it is possible to use sand and fillers [9, 10]. Micro-silica, fly ash, the dust of various industries, fine-ground slags and ash slags, glasses, etc. can be used as filler.

Depending on the improvement and giving of the required characteristic or several characteristics, it is possible to use all known mono- or polyfunctional powdered dry chemical additives (plasticizers, adhesives, retarders, or accelerators of hardening, etc.). Substances of organic and inorganic origin, as well as mixtures thereof, can be used as dry chemical additives [11, 12].

2 Methods

Determination of the thermal conductivity coefficient of polystyrene concrete using secondary polystyrene granules was carried out on samples-plates with a size of 150x150x25 mm, made by cutting from the middle part of the block with a size of 200x300x600 mm. The sample plates were tested on the ITS-1 device.

Samples of polystyrene concrete plates on secondary polystyrene with a size of 100 x 100 x 20 mm have been prepared for shock load testing. The tests were carried out on a dynamic pipe with a length of 400 mm and a diameter of 50 mm. Cyclic shock loads were created during the free fall of a steel ball with a diameter of 48 mm and a mass of 455 g. The work of gravity during the fall of the body was calculated according to the generally accepted formulas of the physics course.

3 Results and Discussion

The technological line for the production of polystyrene concrete includes sequentially installed and technologically connected closed warehouses and silos of raw materials, a multi-cell hopper with dispensers, a feeding hopper, a mixing plant, conveyors, a pre-hardening chamber, devices for cutting polystyrene concrete blocks, a finished product warehouse. Distinctive from the technological line for the production of foam and aerated concrete is that it is additionally equipped with a rotary crusher for crushing foams with an appropriate conveying device, and for mixing all components it is equipped with a comb or screw mixer.

The technological line works as follows.

The foam is brought by rail or motor transport, unloaded into a closed warehouse. Next, the foam is fed into a rotary crusher. Unloading and feeding of polystyrene into the rotary crusher is carried out manually. The resulting crushed polystyrene granules are sent to their cell of the multicellular hopper using a pneumatic transport.

Dry chemical additives are transported by rail or motor transport in plastic barrels or multi-layer bags. Next, the chemical additive is sent to a multi-cell hopper with the help of a forklift, where the packaging is steamed into a separate cell.

Mineral binders are transported by rail or motor transport and are unloaded into silos using pneumatic transport. Next, the binder is sent by a screw conveyor to its cell of a multi-cell hopper.

Fillers in dry powder or dust-like form are transported by rail or motor transport and are sent to their silo with the help of pneumatic transport. From the silo, the filler is sent by a screw conveying device to its cell of a multi-cell hopper.

Depending on the type of polystyrene concrete, the components located in the multi-cell hopper are weighed using weighing dispensers with further dispatch by a belt conveyor to the mixing plant. Weight dispensers are located under a multi-cell hopper.

First, the necessary portion of water is pumped into the mixer. Then a portion of cement is added. Cement is mixed with water. With this sequence, cement dough is obtained without the formation of lumps. Next, polystyrene, a hardening accelerator, and sand are added to the cement dough. Mixing a mixture of cement with water, polystyrene, a hardening accelerator, and sand is carried out for 5-7 minutes until a homogeneous mass is formed. The finished polystyrene concrete mixture is poured into beam molds with a size of 300x600x3000 mm.

The preliminary hardening of polystyrene concrete in molds takes place in a maturation chamber with a temperature of 50-70 °C. The heat treatment time depends on the composition of the polystyrene concrete mixture and is 12-24 hours. After preliminary hardening, the blocks are unformed and cut into the appropriate sizes in agreement with the customer.

Blocks of appropriate sizes are placed on pallets and wrapped with plastic wrap. Usually, 1 m^3 of products is placed on a pallet. The final hardening of polystyrene concrete blocks on pallets takes place in the finished product warehouse for 28 days.

According to the above technology, samples of polystyrene concrete were made, which include Portland cement without additives, porous filler - secondary crushed polystyrene, and a hardening accelerator - sodium sulfate Na_2SO_4 and SWR - saponified wood resin (Table 1) and tested for strength indicators. It is concluded that according to the strength indicators of polystyrene concrete on secondary polystyrene, it can be attributed to thermal insulation, as well as to structural and thermal insulation materials [13].

Table 1. Compositions of polystyrene concrete on secondary polystyrene

№	The composition of polystyrene concrete					
	cement, kg	sand, kg	hardening accelerator, kg		water, liter	secondary polystyrene, m^3
			name	quantity		
H-1	295	35	Na_2SO_4	3,5-4,5	175	1,5
H-2	305	35	Na_2SO_4	3,5-4,5	186	1,5
H-3	315	35	Na_2SO_4	3,5-4,5	192	1,5
H-4	350	-	SWR	0,35-0,4	200	5,5 kg

The thermal conductivity of polystyrene concrete on secondary polystyrene of the same composition was studied on plate samples with a size of 150x150x25 mm (Fig.1). Plate samples were tested on the ITS-1 device to determine the thermal conductivity coefficient (Fig. 2). The principle of operation of the device is based on the creation of a stationary heat flow passing through the flat sample under study. By the magnitude of this flow, the temperature of the opposite sides of the sample, and its thickness, the thermal conductivity of the sample is calculated. The test results are shown in Table 2.

Fig. 1. Samples-plates

Fig. 2. Thermal conductivity testing of samples

Table 2. Thermal conductivity of polystyrene concrete on secondary polystyrene

Sample numbers	Power consumption P,W	Thermal resistance R, $m^2·K/W$	Heat flux density q, W/m^2	Coefficient of thermal conductivity, λ,W/m·K
H-1	0.469	0.2184	96.03	0.1305
H-2	0.211	0.2597	46.42	0.0578
H-3	0.313	0.2104	65.98	0.0870
H-4	0.460	0.2387	91.86	0.1278

The measurements and calculations performed showed that the thermal conductivity of polystyrene concrete from secondary crushed polystyrene is 0.0578-0.1305 W/m·K and depends on the density and strength of polystyrene concrete.
The impact resistance of polystyrene concrete was assessed by the formation of depressions from the fall of a steel ball and the formation of cracks after every 10 drops of the ball on the surface of the sample. The test results are shown in Table 3.

Table 3. Testing of samples for shock loads

Sample number	Formation of depressions, mm				
	Number of ball drops, pc.				
	10	20	30	50	100
H-1	11.0	13.6 (17)	Cracking	-	-
H-2	14.5	18.7	19.1	20.8	25.5
H-3	8.1	11.2	12.7 (27)	Cracking	-
H-4	7.9 (8)	Cracking	-	-	-

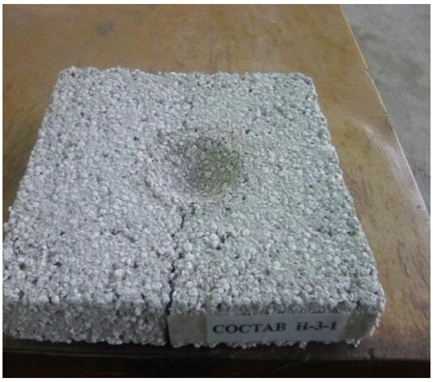
The number of impacts of the ball, after which cracks were found in the samples, is given in parentheses.

As can be seen from the data in Table 3, cracks were found on the samples of polystyrene concrete from secondary polystyrene and SWR (sample H4) after 8 impacts of the fall of the steel ball with the formation of depressions equal to 7.9 mm. The nature of the destruction of the sample is shown in Fig. 3.

Fig. 3. The nature of the destruction of the control (H-4) sample

Polystyrene concrete on secondary polystyrene, where Na_2SO_4 was used as a hardening accelerator, withstands shock loads much more compared to the control sample. Thus, on the samples of H-1, the formation of similar cracks is observed after 17 impacts and the depth is 13.6 mm (Fig.4, a). And on the H-3 samples, the formation of cracks is observed after 27 impacts of the ball, and the size of the depressions is 12.7 mm (Fig.4, b), whereas cracking on the H-2 samples is not observed even after 100 impacts and the formation of depressions is equal to 25.5 mm (Fig. 5).

a



b

Fig. 4. The nature of the destruction of the sample H-1 (a) and H-3 (b)

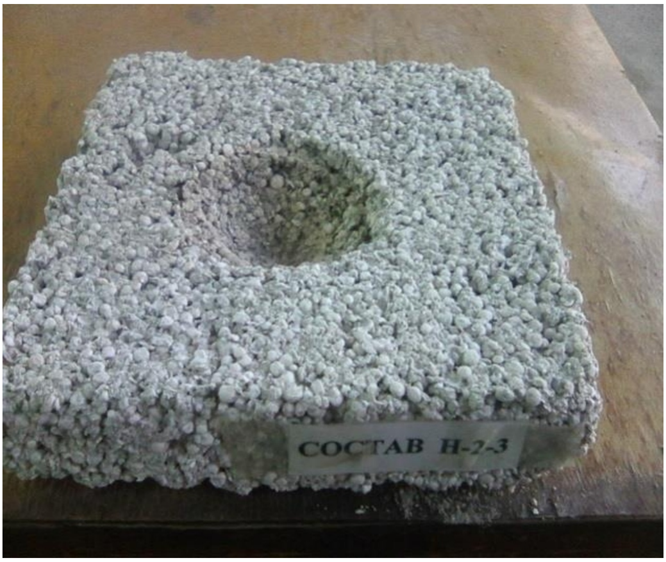


Fig. 5. The appearance of the sample H-2 after the impact strength test

According to the course of physics, it is known that if a body of mass m is uniformly lifted to a height of H with the help of force F, then the force performs work equal to potential energy. It is also known that the potential energy corresponds only to the work performed by gravity during the free fall of the body [14]. The results of calculations of the work of destruction in the free fall of a steel ball are given in Table 4.

Table 4. Calculated values of the work of destruction of samples

Sample number	Ball mass, kg	Ball drop height, m	The work of destruction, J
H-1	0.445	0.4	not less than 30 more than
H-2	0.445	0.4	178.5
H-3	0.445	0.4	not less than 48
H-4	0.445	0.4	14,28

From the given data, Table 4, it can be seen that for the destruction of a sample of 100 x 100 x 20 mm of mass-produced polystyrene concrete on secondary polystyrene using SWR as a hardening accelerator (sample H-4), it is sufficient to perform work with a free fall of a steel ball weighing 0.445 kg equal to 14.28 J, whereas, for the destruction of a sample of similar sizes using Na_2SO_4 as a hardening accelerator, the cost of work from 30 to 48 J (samples H-1 and H-3) is required.

It should be noted that the magnitude of the destruction work depends not only on the composition of polystyrene concrete but also on the polystyrene concrete hardening accelerator used. If we take a concrete example, comparing Na_2SO_4 and SWR, we can see the superiority of the first hardening accelerator over the second. Samples of H-2 have no signs of destruction even after the work of the impact is equal to 178.5 J.

4 Conclusions

The organization of production of polystyrene concrete products according to the proposed technology can be carried out at enterprises for the production of concrete and reinforced concrete, cement, dry building mixes, as well as an independent production. This technological line makes it possible to produce all known compositions of cellular concrete and polystyrene concrete. To avoid the dusting of materials during transportation, conveyor belts can be designed in sealed enclosures.

The thermal conductivity coefficients for polystyrene concrete on a secondary crushed polystyrene aggregate were determined and the dependence of the thermal conductivity of the sample on the density and strength of polystyrene concrete was established.

In terms of impact resistance, polystyrene concrete can be attributed to viscous materials capable of extinguishing large energy shock loads. The magnitude of the destruction work depends not only on the composition of polystyrene concrete but also on the polystyrene concrete hardening accelerator used. Polystyrene concrete samples using Na_2SO_4 as a hardening accelerator can absorb the impact energy of more than 178.5 J.

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