Investigation of the Strength Characteristics of Shotcrete as a Function of the Technological Parameters of the Application

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Abstract. The technology shotcreting of vertical surfaces in construction with application of pneumoframework moulds is rather studied, however the technological modes of a shotcreting of horizontal surfaces of pneumoframework moulds demand justification. Experimental studies have determined rational parameters of the technological modes of a shotcreting. By the results of the experimental studies there has been determined the character of the influence of technological parameters on the structural formation of construction material. Various parameters of a torch of shotcrete are set. The main vibration characteristics of fabric of a flexible pneumatic mould are established. Graphic dependences of durability are defined shotcrete on compression from the key technological parameters of process of drawing shotcreting.

1. Introduction

In accordance with the scientific experience accumulated to date [1…6], the strength of shotcrete - concrete with a constant granulometric composition and water - cement ratio is determined by the conditions of compaction of the mixture during the direct laying. Due to the fact that the main purpose of the study is to achieve design strength, the experimental part of the work focuses attention on studying the configuration of the concrete mixture's torch when it is applied to the horizontal surface of the pneumoframe formwork in terms of ensuring optimum compaction conditions [7…9].

According to the laws of theoretical mechanics, one can imagine the process of applying shotcrete-concrete particles to a deformable surface in the following way. At the moment of departure of the shotcrete-concrete particles, due to the pressure of the compressed air, a sufficiently high speed of flight. Then they move in a flare with an expanding airflow, both the particles of the mixture and the air flow lose their speed [10…12].

Experimental studies of parameters of a torcrete - concrete torch during its application to the horizontal surface of a pneumoframe formwork were performed with the following main parameters: distance H between the nozzle and the surface to be treated; diameter D of the nozzle (10 to 30 mm); angle expansion of torch concrete mix α (deg); performance of the shotcrete-machine Q (m³); diameter of the torch spot d (cm) [13…17].
Analysis of the experimental data made it possible to establish that the dependence of the change in the spot diameter on the parameters Q, H, D listed above is close to linear. In parallel with carrying out researches with the purpose of reception of the samples necessary for tests on durability, the control over the form of a stain was carried out [18].

The study of the process of application of shotcrete - concrete on the fabric sample allowed to establish the character of the distribution of the concrete mixture over the area of the spot. The bulk of the mixture lies along its outer contour. This is due to the fact that in the falling jet the particles of the solution in the expanding air flow have a high kinetic energy, which is converted into a potential one, and ejects the mobile concrete mixture into neighboring zones.

The nature of the distribution of concrete on the surface of the fabric sample was determined by measuring the thickness of the concrete layer applied for a short (about 2 sec.) operation of the nozzle with a steady spray pattern. The thickness of the concrete along the edges of the spot reached 30-40 mm, and in the thinnest layer (in the middle zone) 20-25 mm. Figure 1 shows the distribution of the concrete mix in the spot.

![Figure 1. The scheme of distribution of the concrete mix in the spot](image)

Examination of the applied spot of the shotcrete showed that it has a very uneven surface of the concrete mix. Observing the change in the shape of the crater of the concreting spot, the author came to the conclusion that a change in the shape of the crater can provide information on how optimally the combination of the main parameters of the approach velocity of particles and elementary mass from the point of view of ensuring optimum compaction conditions.

Experiments have shown that at a small distance (about 0.3 m) from the nozzle to the pneumoformwork, a strong spray of the concrete mix occurs due to the high kinetic energy of the particles and their significant rebound from the surface. Reducing the kinetic energy (for example, increasing the distance from the nozzle to the surface), we get a "crater", the shape of which is shown in the figure. As a result, by changing the approach speed and elementary mass by varying the technological parameters, it is possible to obtain a spot of concreting, all the zones of which have the same thickness. It can be assumed that with this combination, ideal compaction conditions are ensured and, as a consequence, optimum strength. Further variation in order to increase the detected influence of technological factors on the shape of the crater of the concreting spot will lead to the formation of an elevation in
the middle zone. This indicates that, with this combination, the kinetic energy of the particles is insufficient to ensure optimum concreting conditions [19].

During the experiments, the compaction quality was monitored by examining the pore structure of the shotcrete. The study was carried out using a linear method of optical microscopy, which allowed to study the structure of the material in a wide range. Samples of shotcrete - concrete were sawed along the central part perpendicular to the plane of the application layers. The cutting surface was studied in reflected light with a binocular magnifier at a 50-fold magnification. During the experiments, the influence of all technological factors of the shotcrete process on the porous structure of the shotcrete samples was investigated.

With a nozzle height from the surface of 0.5 m, the number of pores is 2.5 to 3.0%, and at a height of 1.0 m - from 2.3 to 2.5%. At a height of 1.5 m, the porosity values vary between 3.0 and 4.0%. Thus, at a spraying height of 1.0 m, the porosity has a minimum value.

As a result of investigation of the structure of the shotcrete - concrete samples, depending on the tension force of the textile pneumoframe formwork, it is established that as the tension increases, the material becomes more dense (the porosity of the material, on the contrary, decreases). The figure 2 shows photographs of thin sections with a weft tension of 5.0 and 25 kN/m and identical other parameters [20].

![Figure 2](image)

**Figure 2.** Photos of samples with different tissue tension: a) N = 5.0 kN/m; b) N = 25 kN/m

In the course of further research, the effect on the porosity of shotcrete concrete on the plant productivity is experimentally determined. This dependence is as follows: with an increase in the shotcrete-machine capacity in the range from 1.5 to 3.0 m³/h it significantly decreases (the minimum value at Q = 3.0 m³/h), and with a further increase in capacity to 4.8 m³/h it also increases.

**Conclusions.** In studies on the optimal parameters of the nozzle diameter and the distance from the nozzle to the pneumoframe formwork, it is confirmed that with increasing tension of the pneumoframe formwork, its negative effect on the compacting process of the concrete mix decreases and, consequently, the strength increases. Increasing the diameter of the nozzle leads to a decrease in the strength of the concrete, which is apparently due to a decrease in the flow velocity and, accordingly, the compaction of concrete particles upon falling onto the surface.

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