Electrostatic Fiber-reinforced Concrete: New Opportunities in Construction

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Abstract: A new type of additive technology in construction is proposed - the so-called electrostatic molding of products and structures from fiber-reinforced concrete. The peculiarity of the method is that the electrostatic deposition of layers of dry concrete mix and reinforcing fibers on the shaping frame occurs without impact and noticeable mechanical impact, in contrast to the coating technology, for example, with shotcrete. A layer of fiber-reinforced concrete electrostatically deposited on the frame, after moistening and a short time delay, increases the strength of the shaping frame. As the number of layers of concrete increases, the strength of the frame increases, many times ahead of the load from an increase in the mass of concrete. Therefore, the shaping frame can be made lightweight. This greatly simplifies its production. Therefore, reinforcing wire, wire mesh and thinned coarse fabric made of hydrophilic fibers can be used for the frame of the structure. This is a significant advantage of the new technology. When, after some time, the electrostatic concrete gains the necessary strength, the structure is covered with glass fiber reinforced concrete from the inside using shotcrete. It is necessary to carry out studies to determine the limits of applicability of the method in various areas of construction.

1 INTRODUCTION

Apparently, the first truly additive technology in the world was electroplating, discovered by B.S. Jacobi in 1837. In electroforming, a new object is created due to metal ions, which, under the action of an electric field, purposefully move and settle on the cathode, repeating its relief to the smallest detail (Dr. Jacobi, 1840). In recent decades, additive technologies based on the layer-by-layer growth of three-dimensional objects using computer 3D technologies have been increasingly used. This applies to products made from a variety of materials.

One of the first additive technologies for builders can be considered the technology of shotcrete, which appeared at the beginning of the 20th century. This is a productive method, but application of shotcrete requires a solid wall, forming surface, or single-sided formwork. Despite the fact that the concrete jet is highly dispersed, upon impact, the high-speed jet exerts strong pressure on the barrier (Bazhenov, 1984). Therefore, shotcrete is used where there is a solid foundation - for repairing destroyed reinforced concrete, strengthening the walls of pits, tunnels and foundations, restoring hydraulic structures, etc. The construction 3D printer that appeared at the end of the 20th century is another example of additive technology in construction (Dominguez, 2013; Fedorov, 2017). Despite all its shortcomings, the construction 3D printer has already proven itself as an economical way to build low-rise housing.

For more than half a century abroad, especially in Germany and the USA, and later in Russia, tents and tent coverings made of film-fabric materials have been used. Their disadvantage is that awnings and coverings in the form of technical fabrics require the creation of a strong support contour with tension and anchor devices for the stability of the structure against strong winds and sometimes snow loads. When studying such coatings from soft shells, it is noteworthy that steel posts, solid or prefabricated arches, guy wires and anchors, apparently, are much

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larger in weight and cost than the technical fabrics for tent covering themselves. Despite the often complex technology of cutting technical fabric and its sewing or welding (Patent RU 2622571, 2017).

Most of the coatings of large long-term structures are built from rigid materials - from reinforced concrete and precast concrete, and sometimes sheet metal is used for membrane coatings. These materials have long been widely used in construction practice (Ledenev, 2016; SP 52-117-2008, 2008). The use of prefabricated reinforced concrete slabs or metal membrane coatings requires a well-equipped and capital-intensive production base for its implementation.

Technical solutions are known, based on the use of mesh or fabric materials in the form of a shell, for fixing the spatial shape of which the impregnation of the shell material with a fixing composition is used. For this purpose, curing compounds based on epoxy resins, acrylic compositions and other compositions of polymeric substances are used. For example, in order to fix the shape of the shell impregnated with a hardening composition, the contour elements of the shell are made in the form of a sleeve from the shell material, impregnated or filled with a hardening composition (A.s. 935578 MKL E 04 B, 1982).

The disadvantages of using polymer curing compositions to fix the shape of the shell are that this technology is characterized by high labor intensity of manufacture and insufficient rigidity and strength of the cured shell contour. Since polymers have strength indicators and modulus of elasticity many times lower than those of steel. In addition, work with curing compositions is strictly limited in time, since the viscosity of the prepared compositions increases rapidly over time. Working with curing compounds is associated with unhealthy epoxy resins, acid hardeners, plasticizers and solvents, especially during formulation and curing.

2 RESEARCH METHODS

In Russia, a new type of additive technology has been proposed - the so-called electrostatic molding of products and structures from fiber-reinforced concrete (Kokoev, 1997). The new technology gives more creative freedom to the architect. It is appropriate to note here that each new technology sooner or later finds its niche in the construction practice. For example, the prominent French constructivist architect Le Corbusier in the first third of the 20th century contributed to the widespread use of concrete and glass in architecture with his projects (Le Corbusier, 2004; Andrew Ayers, 2004). He is also known worldwide for his pioneering work on precast concrete. In 1914, Le Corbusier created and patented the Dom-Ino House project, which was essential for his creative biography. In fact, this was the very first frame-type house project for serial construction. In this project, he for the first time foresaw (together with engineer M. Dubois) the great possibilities of building from large-sized prefabricated reinforced concrete elements - flights of stairs, floor slabs, columns, etc.

But back to our topic. It is better to explain the essence of "electrostatic" fiber-reinforced concrete with an example. The selected objects are related to the construction of hip roofs that crown centric buildings, both in religious and civil buildings. Coverings in the form of tents are also found in the construction of cottages, exhibition and trade pavilions, tourist centers and campsites. The tents can be with double negative Gaussian curvature and prismatic with zero or negative curvature (see figure).

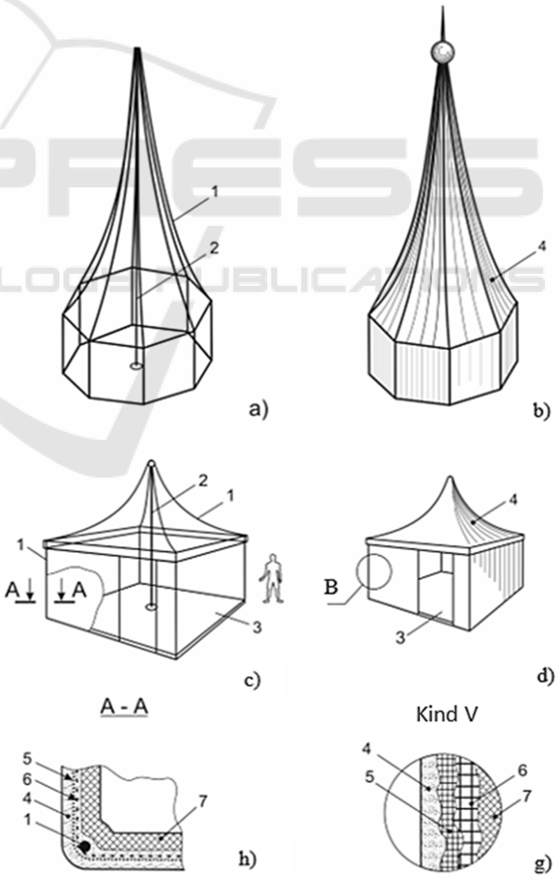

Figure 1: Electrostatic fiber-reinforced concrete - new opportunities in construction.

Before moving on to the technology of the method, it should be noted that the electrostatic deposition of layers of dry concrete mix on the shaping frame occurs without impact and noticeable mechanical impact, in contrast to the coating technology, for example, with shotcrete. The first electrostatically deposited dry layer of fiber-reinforced concrete, after moistening and a short time delay, significantly increases the strength of the shaping frame. As the number of layers of concrete increases, the strength of the frame rapidly increases, many times ahead of the load from the increase in the mass of fiber-reinforced concrete.

a) the shaping frame of the prismatic tent, made of wire reinforcement;
b) a prismatic tent, covered on the outside with fiber-reinforced concrete, and on the inside with shotcrete glass fiber-reinforced concrete; c) pavilion wire frame with prismatic or conical tent with negative Gaussian curvature; d) a pavilion covered on the outside with fiber-reinforced concrete, and on the inside with shotcrete glass-fiber-reinforced concrete; h) section A-A; g) view B.

1 - ribs of the shaping frame made of reinforcing wire, 2 - inventory mast, 3 - base (floor) of the structure, 4 - layers of concrete deposited by electrostatic sprayers; 5 - thinned burlap, 6 - welded or woven mesh, 7 - shotcrete layer of glass fiber reinforced concrete.

Thus, the shaping frame can be made lightweight. Therefore, for the manufacture of the framework of the structure, it is possible to use reinforcing wire, welded or woven wire mesh, duplicated with a thinned coarse fabric (sparse burlap) made of jute and other hydrophilic fibers. This reduces the labor intensity and metal consumption of manufacturing a shaping frame for low-rise buildings. In addition, the method allows the use of a water-cement ratio close to the theoretical one for a given concrete composition. The optimal W/C value should provide savings in cement without reducing the strength of fiber-reinforced concrete. So, the shaping frame of the building is made of reinforcing wire, the openings are closed with steel welded or woven mesh. Outside, thinned burlap made of jute and other hydrophilic fibers is attached to the mesh. In this case, the cells in the wire mesh are desirable from 30 mm in size and above, and on the burlap the cells in the light should be in the range of 5-12 mm. In the manufacture of a shaping frame for a tent with a double negative curvature, a flexible woven steel mesh is used, thinned burlap is attached to the mesh from the outside. Form limited areas of the surface of double curvature, using the property of a woven mesh and burlap to change the density of the weft and warp threads.

The burlap is moistened for electrical conductivity, the shaping frame is grounded, and using a manipulator with electrostatic sprayers, the burlap, together with the underlying mesh, is covered with a dry concrete mixture containing reinforcing fibers. The process of coating the shaping frame with a dry mix is affected by the electrical resistivity of cement particles and other components of the dry mix. Of the industries where electrostatic technology is used, it has been established by practice that the area of optimal electrical conductivity of particles for their electrostatic deposition (cement, fine sand, fly ash, fiberglass, etc.) has a wide range - from 107 to 109 Ohm·m (Petzold, 1990; Lagarias, 1960).

The settling of the dry concrete mix and the wetting of the dry concrete mixture with water mist must be separated by time and/or distance along the building surface so that the high humidity air does not reach the electrostatic sprayers. It is better to moisten the applied layer of dry concrete with a cold fog generator. Fog generators spray water with droplets no larger than 50 microns. The cycles of coating with a dry mixture and moistening with water are repeated until the required thickness of fiber-reinforced concrete is obtained. Between cycles, time delays are made for the fiber-reinforced concrete to gain initial strength.

3 RESULTS AND DISCUSSIONS

To prepare a dry mix of concrete, hydrophilic quick-hardening Portland cement with fine mineral additives and fibers is used. Instead of fine sand, depending on the requirements for the structure and its purpose, mineral powders are used - finely ground waste from stone processing or ash and slag waste, fly ash from electrostatic precipitators of power plants, perlite powder, volcanic ash, cement dust from electrostatic precipitators of cement plants and other finely dispersed materials of natural and technogenic origin (Nakhaev, 2015; Salamanova, 2019; Salamanova, 2018).

For fiber-reinforced concrete, reinforcing fibers are used - alkali-resistant glass, basalt, carbon (Polyacrylonitrile; Hong, 2014), etc. The fibers must first be freed from lubricants and other hydrophobic substances. This condition provides good wetting with water with the addition of surface-active substances (surfactants) of the concrete mixture and fibers and contributes to the work of capillary forces to compact the layers of fiber-reinforced concrete. If water-soluble polymers are added to water to improve the properties of fiber-reinforced concrete, then the addition of surfactants is often not required, since many water-soluble polymers themselves have good surface activity. To increase the strength of some objects after the strength of the electrostatically deposited layers of fiber-reinforced concrete, the structures can be covered with glass fiber reinforced concrete from the inside using shotcrete.

4 CONCLUSIONS

Using the technology of electrostatic molding of products and structures made of fiber-reinforced concrete will give the following technical and economic effect:

1. Reducing the labor intensity and metal consumption of manufacturing shaping frames of products and structures.
2. In the new technology, for the first time, it became possible to regulate the W / C over a wide range, regardless of the complexity of the product shape. Through the use of a water-cement ratio close to theoretical, savings in cement should be achieved without loss of concrete strength.
3. The use of "electrostatic" fiber-reinforced concrete for the construction of low-rise buildings in appropriate climatic conditions will increase the durability of structures, as well as reduce the cost of their construction.

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