Overview of robotic shotcrete technologies with basalt reinforcement

Thomas Bock[1], Viacheslav Aseev[2] and Alexey Bulgakov[2,3]

[1]Technical University Munich, Germany
[2]Southwest State University, Russia
[3]Central Research and Development Institute of the Ministry of Construction of Russia, Russia
thomas.bock@br2.ar.tum.de, swsu_aseev@mail.ru, a.bulgakow@gmx.de

Abstract –

The article provides an overview of current developments in the technology of shotcrete surfaces of building elements, examples of construction robots that provide robotization of such technologies are presented. The article also presents the shotcrete technology, which will improve the quality of building structures and automate the shotcrete process using basalt fiber as reinforcement. Also, a model of reinforcement of the processed building structure according to the proposed technology is given.

Keywords –

Shotcrete; Basalt; Robotization; Reinforcement

1 Introduction

During the reconstruction of historical buildings and structures, it becomes necessary to strengthen and interface individual structural elements or the entire building as a whole. The key point in carrying out such work is the preservation of architectural expressiveness. Basalt fiber is one of the materials used to replace the metal components of structures, equipment and products, being inexpensive, lightweight and affordable, as well as resisting corrosion. These facts are also evidenced by modern studies [1,2,3].

Preservation of architectural forms can also be achieved by shotcrete technology, which has proven itself as a technology that provides a process of reinforcement when working in conditions of negative temperatures, minimal water absorption due to the compaction of the solution, resistance to aggressive environments, sudden changes in temperature/moisture, as well as laying without the need for installation formwork.

When investigating shotcrete, it is also necessary to consider the use of traditional reinforcement or the possibility of reinforcing structures with metal or non-metal fiber components. This is relevant in the production of work related to the construction, repair or restoration of load-bearing and enclosing building structures of buildings and structures.

Modern methods of shotcrete today include technologies such as "dry" and "wet" application. "Dry" gunning is characterized by the possibility of applying thick layers of material, as well as high productivity [3]. In turn, "wet" gunning has such advantages as the uniformity of the composition of the material and the ability to work in cramped conditions. Analysis and generalization of the advantages and disadvantages of these technologies reasonably set the task of using an effective innovative, mobile, low-budget technology that allows combining the advantages of shotcrete methods and leveling the disadvantages.

2 Shotcrete technology

Speaking of modern shotcrete technology, it is assumed that it combines as many positive characteristics of existing technologies as possible, and also includes a new equipment configuration. So, a group of engineers led by Chelpanov V.G. the technology of the “semi-dry” method of concrete spraying was developed and implemented [4] (fig. 1).

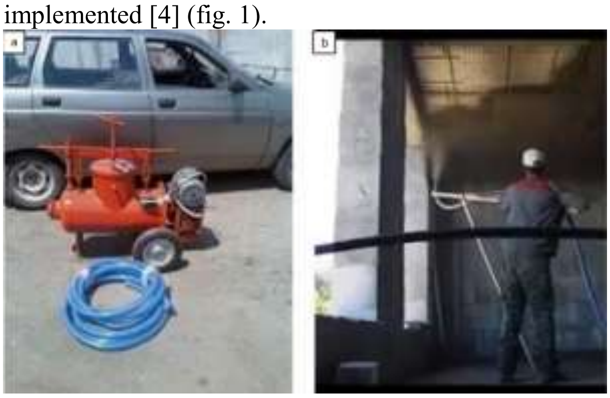

Figure 1. Mobile equipment and technology for applying semi-dry sprayed concrete

This technology occupies an intermediate position between dry and wet shotcrete, using the advantages of both. In the proposed technology, the solution is supplied through the material hose in portions with air gaps, which increases the efficiency of the supply due to the piston action of the portion. This allows you to easily hold the sleeve and barrel in your hands, as it is semi-empty and light. Trial equipment for applying sprayed concrete by the semi-dry method was created and tested, which significantly expands the possibilities of using the technology to solve various engineering problems.

However, the technology of applying semi-dry shotcrete involves the use of equipment of a special configuration. The modern development of barrel modification (shotcrete nozzle) was developed by Russian researchers (fig. 2) [5, 6].

Figure 2. Shaft modification for semi-dry shotcrete

The resulting process of semi-dry shotcrete using a modified barrel allows you to apply a layer of up to 250 mm on a vertical surface [4].

As a result of improvement, large-scale testing and implementation of this technique and equipment at the leading enterprises of Russia on various shotcrete equipment, using various dry mixes, effective production results were obtained. A cardinal reduction in the rebound of dry mixes is achieved by 5 times and dust content in the workplace by more than 6 times, which makes it possible to obtain a significant economic, environmental and social effect (fig. 3). Positive results were also established when applying fiber-reinforced concrete [7].

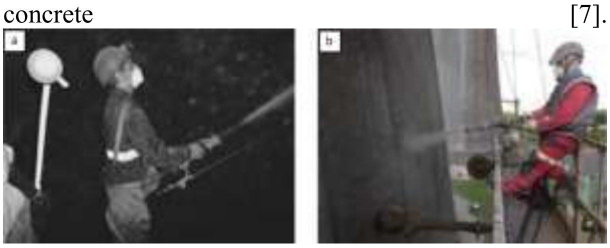

Figure 3. Shotcrete using a modified shaft configuration in the shaft (a) and at a height (b)

At the same time, materials and equipment for the implementation of this technology are significantly cheaper than those offered on the market, which ultimately reduces the cost of the product and allows you to successfully compete in the market for services for this type of work.

However, in case of buildings with higher criticality rating we need to minimize the human factor, the reliability of the operations performed, and often increase the speed of work, which indicates the natural need for robotization of the shotcrete process.

3 Shotcrete robotic technologies

The use of programmable robots in the construction process certainly has its advantages, but it should be borne in mind that in order to implement this idea, it is first of all advisable to conduct a comparative analysis of existing robots. For the introduction of robotics in the shotcrete process, it would be advisable to give examples of the successful use of installations similar in type of work. One such construction of a mortar applicator is shown in fig. 4.

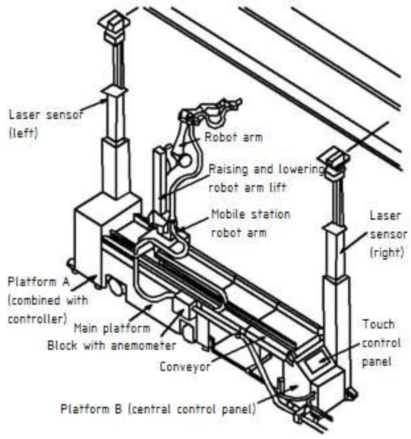

Figure 4. Configuration of a modern robot for outdoor finishing works

The main purpose of a modern robot for outdoor finishing work is spraying decorative coatings and applying paint compositions. The robot arm is placed on the lifting platform and moves along it, which significantly expands the capabilities of the seven-link manipulation system. The manipulator is the basis of the spray mechanism equipped with a nozzle. The positioning device of the robot is equipped with laser sensors, which allow you to control the distance to the main beam, on which the painting robot is suspended, with great accuracy. The platform is equipped with a control device that controls all links and components of the robot. The use of an active display to control the robot made it possible to easily set the parameters of the robot's movement. The presented design is cumbersome and requires significant refinement.

In contrast to the considered robot configuration, in fig. 5 shows an improved design of the manipulator, designed for applying solutions by spraying with compressed air. The wall surface robot is mounted on a light platform moved by a winch along the wall surface. This robot can also clean walls, or be used to check the quality of tiles on a wall surface.

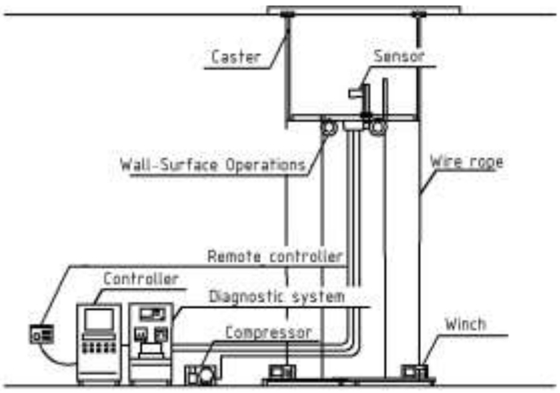

Figure 5. Design of improved manipulator

An analysis of construction robot designs shows that it is advisable to create specialized manipulators and robots for the robotic application of cement compositions, which provide the preparation of vertical and horizontal surfaces. Among the various solutions for such robots, one can distinguish mobile and mounted on a lifting platform manipulators. Moreover, for the movement and orientation of the processing tool, 5 degrees of freedom are sufficient, while it is advisable to use a block-modular design.

The calculation of concrete structures by the finite element method convincingly proves that where there is no active ingress of moisture, the destruction of concrete occurs due to forced natural vibrations of the structure. The first cracks in the structure appear simultaneously with the start of its operation. The design initially contains concrete zones, which during operation either crack or tear off part of the concrete. And only in the process of further operation, chlorides appear, corrosion of the reinforcement due to the initial power cracks. As a conclusion: the application of non-fiber-reinforced materials to a locally damaged surface leads to the appearance of cracks and rejection of materials, since these materials do not work in tension.

4 Reinforcement technology

Given the need for reinforcement, a solution was developed that provides an easy installation of reinforcement, which can be integrated into the workflow of construction robots. Below is one of the solutions for reinforcing with basalt fiber rods using the example of shotcrete work on the load-bearing column of a building (fig.6).

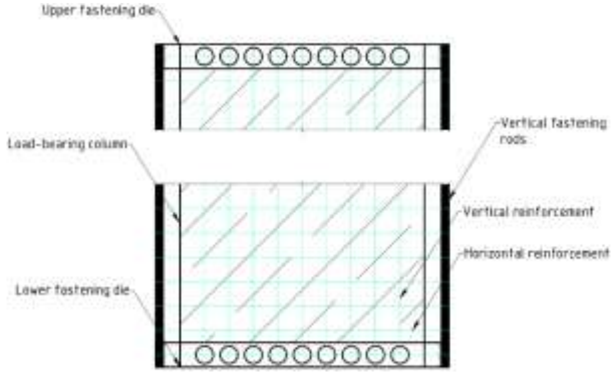

Figure 6. An example of reinforcement with basalt fiber of a load-bearing column before the shotcrete process

A fastening die is attached to the column being processed along the upper and lower faces, the design of which is shown in fig.7. The function of the fastening die is that it serves as an attach-point for tensioning the basalt rod, which, in its turn, reinforces the required volume of concrete. Such a solution makes it possible to robotize the process of strengthening the shotcrete, since the robot installation is implicitly capable of reading information about the location of the fastening die and the features of its location and configuration. After the installation of the structure, vertical fastening rods are also attached to such dies, which serve as an attach-point for tensioning the basalt rod of horizontal reinforcement. After mounting the fixing dies and bandaging the basalt reinforcement along it, the shotcrete process takes place. The dismantling of such dies is not necessary, but rather even undesirable, since, by adhering to the column, they provide the reinforcement with a better connection with the structural element being processed.

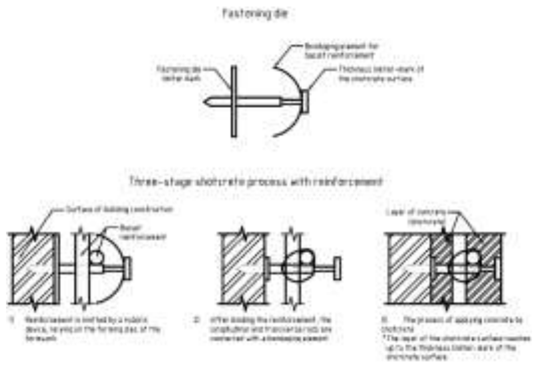

Figure 7. The algorithm of the shotcrete process using basalt rebar rods

5 Discussion

In addition, it is also worth considering that in order to perform shotcrete with basalt fiber reinforcement, it is necessary to take into account the fact that some structural elements can be spherical and other non-planar configurations. Uniform application of solutions over such structures requires modification of existing technologies for robotic shotcrete. Also, to quickly stop shotcrete at the end of the wall or when moving to the ledges of walls and niches, it is still not enough to set the pump alone, because due to the residual pressure in the hose, the solution is still supplied by inertia to the executive body of the plastering tool. Therefore, it is required to have a controllable shut-off valve that can immediately stop the flow of material. There is also a need to ensure the alignment of large irregularities, so the flow of material must be regulated in accordance with their geometric dimensions. This can be realized through the variable productivity of the shotcrete robot, for example, with the help of an adjustable pump or by changing the speed of the plastering tool with its constant productivity.

The analysis of shotcrete robots shows that kinematic schemes with a polar base coordinate system, despite their compact construction, are the least suitable for such robots due to the spherical shape of the working area. More suitable in this case are kinematic schemes with swing axes, due to its great flexibility and compactness. Technical control costs and limited accuracy due to kinematic errors for this scheme are the main disadvantages. Kinematic schemes with a cylindrical base coordinate system, as well as with a rectangular one, are well suited for shotcrete robots, but still with some disadvantages regarding the working area and accuracy. Kinematic schemes with a rectangular coordinate system are best suited for plastering work, which is explained by the good consistency of the rectangular working area of the robot with the usually flat surface of the surfaces being reinforced and increased accuracy due to the ease of orienting the kinematic axes along the given motion trajectories. The costs for the technical implementation of such systems due to simple kinematic links are significantly lower compared to other options. The disadvantage is the large overall dimensions, due to the use of such a scheme for constructing kinematics.

6 Conclusion

Based on the methods described above, it can be concluded that modern technologies naturally lead the process of strengthening the structures of buildings and structures to robotization. The above reinforcement technology also implies the robotization of the process, which will solve a number of existing problems that accompany shotcrete surfaces. It is also worth noting that the use of rebar or fiber as part of the concrete mixture during the shotcrete process is extremely appropriate, given the need to eliminate the shortcomings of this technology for the rehabilitation of facades and surfaces of buildings and structures. Further research involves the analysis and selection of the most optimal of the considered options for shotcrete technology with the further development of a shotcrete installation together with reinforcement with basalt fiber.

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