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CREATION OF POLYURETHANE AND URETHANE FOAM INJECTABLE MATERIALS AND THEIR PILOT PRODUCTION; DEVELOPMENT AND IMPLEMENTATION OF TECHNOLOGY FOR CONSOLIDATING AND REHABILITATING THE DAMAGED CONSTRUCTIONS AND BUILDINGS

The polyurethane and urethane foam injectable materials that are highly competitive with foreign analogues have been designed. A technique for repair and consolidation of cracked concrete and reinforced concrete structures and buildings has been developed. Standard technical documents for the injectable materials and technological processes have been elaborated. A trouble-shooting and repairing complex for implementing the above technique has been designed, installed, and implemented on construction sites. The equipment has been designed and manufactured; a technique for serial production of «A» and «B» components of injectable polyurethane materials has been developed. The pilot batch has been manufactured. Technological processes for preparation and application of the «A» and «B» components of injecting materials in industrial conditions have been elaborated and implemented.

Keywords: injectable materials, rehabilitation, and constructions.

In 2006—2014, the G.V. Karpenko Institute of Physics and Mechanics of the NAS of Ukraine and the *Techno-Resource* Engineering Center of the NAS of Ukraine performed a set of theoretical, research, technical, and engineering works in order to provide the construction and industrial corporations of Ukraine with domestic polyol (A) and polyisocyanate (B) components, as well as with means of technological processes for the serial production of reactive polyurethane and urethane foam injectable composites. In addition, the processes for injecting these composites in cracked concrete and reinforced concrete structures under pressure have been proposed [1—3].

The R&D works and technology for serial production of «A» and «B» components, as well as of polyurethane and urethane foam injectable materials have been made by *Techno-Resource* Engineering Center of the NAS of Ukraine. The technology for consolidation and repair of damaged concrete and reinforced concrete structures has been validated and implemented at enterprises of the Ministry of Regional Development of Ukraine, *Energoatom* of Ukraine, and *Ukrhydroenergo* [4—6].

1. DEVELOPMENT OF POLYURETHANE AND URETHANE FOAM INJECTABLE MATERIALS AND TECHNIQUES FOR THEIR USE AT CONSTRUCTION SITES

Analysis of domestic and foreign patents and publications describing the processes of preparation and use of injectable fluid polymeric materi-

als has showed that the polyurethane polymers and composites based on them have better engineering, technical, and operational parameters than their poly-epoxy, silicone, and acrylic counterparts. Having a relatively low initial viscosity and being able to keep the fluid state for a quite long period (before setting) the polyurethane compositions firmly interact with damages (cracks, corrosion damage, bundles, etc.) that occur during long-term operation of buildings and structures. In addition, the fluidity and reactivity of polyurethane injectable materials are easily adjusted by changing the nature and concentration of «A» and «B» components [7, 8].

Another significant advantage of polyurethane, namely urethane foam, injectable composites is their ability to be structured with significant volume expansion when contacting water. Due to a 10—30 time increase in volume, the foam injected under a pressure of 10—150 atm. tracks not only blocks the cracks in the concrete matrix, but also prevents the water leakages in sewer collectors and hydraulic structures (Fig. 1).

The process of repair and consolidation of damaged concrete and reinforced concrete structures by injection of polyurethane composites consists of the following operations [4]:

- Visual inspection with the use of appropriate tools for the identification of type, size, and other parameters of cracks and defects;
- Engineering calculations to identify the areas and points for injection;
- Drilling of holes in the concrete matrix to reach deep cracks and defects (Fig. 2);
- Injection of fluid polyurethane composites under a pressure of 10—150 atm into the holes in damaged concrete matrix;
- Interaction of «A» and «B» components of polyurethane composites with each other and with the surfaces of concrete and steel bars to form the «concrete — polyurethane — concrete» (steel bar) interfaces at a temperature of 20 ± 5 °C.

The developed composites have been established to comply with technical requirements for

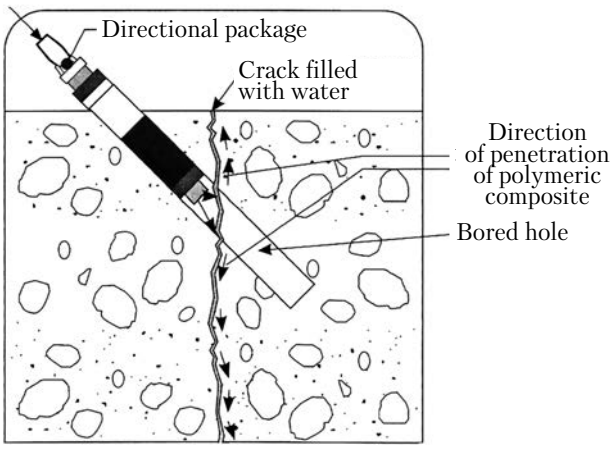

Fig. 1. Injection of polyurethane composition into a through crack filled with water, in concrete structure [11]

Fig. 2. *Techno-Resource* workers drilling holes for injection into a sewage collector on Svobody Avenue in Lviv

injectable polyurethane materials by laboratory tests and have been certified in accordance with UkrSEPRO system by State Consumer Standard Committee of Ukraine. The injectable polyurethane materials and solid inserts based on them comply with TU U V.2.7-24.1-13 803953-017-2011 «*Techno-PUR* Polyurethane System and Regulations for Industrial Use of *Techno-PUR* for the Repair of Concrete and Reinforced Concrete Structures by Injection Technique» [3].

2. THE DEVELOPMENT AND IMPLEMENTATION OF MOBILE COMPLEX FOR TROUBLE-SHOOTING AND REPAIR

To implement the technique for rehabilitating the concrete and reinforced concrete structures by polyurethane injections a mobile trouble-shooting and repairing system has been designed and implemented (Fig. 3). It consists of the following elements:

Fig. 3. Mobile diagnostic and recovery complex during repair of sewer collector on Svobody Avenue in Lviv

1) *FOTON BJ* 1043 van;

2) A trouble-shooting device having a video head for photographing the inner surfaces of underground sewers and culverts and a cable for transmitting information to a computer;

3) A computer for recording and engineering processing of trouble-shooting results from the video head of mobile device;

4) A mobile device for cleaning the damaged internal surfaces of underground steel, concrete, and reinforced concrete structures before the repair works;

5) An injector for the repair of utilities structures;

6) A device for the repair of inaccessible internal surfaces of underground utilities by coating with and fixing polymer mates with adhesive sublayer; and

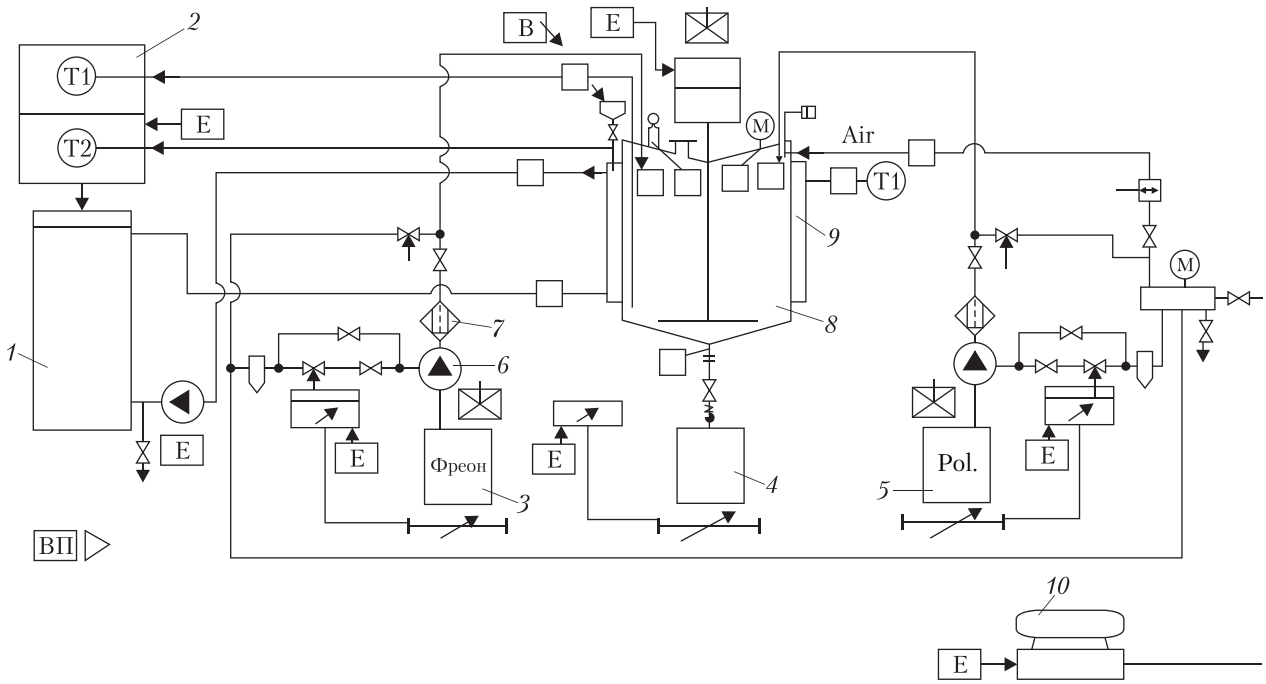

Fig. 4. Flowsheet of pilot workshop producing «A» polyol components of polyurethane injectable composites: *1* — container with polyols; *2* — thermal control system; *3* — container with freon; *4* — barrel for polyol; *5* — tank for additives; *6, 7* — means for controlling supply of components; *8* — reactor mixer; *9* — heat stabilizer; *10* — compressor

7) petrol electricity generating plant (output of 2.5-3.0 kW) and other auxiliary equipment.

3. THE PILOT PRODUCTION OF «A» AND «B» COMPONENTS OF INJECTABLE POLYURETHANE MATERIALS

To produce commercially the domestic polyol (A) and polyisocyanate (B) components for preparing injectable polyurethane composites at construction sites, the respective process equipment has been designed and manufactured. A flow sheet for the production of polyol «A» component at the *Techno-Resource* Engineering Center of the NAS of Ukraine is given in Fig. 4; the reactor section is showed in Fig. 5; a flow sheet for the production of «A» and «B» components is presented in Fig. 6.

The polyol (A) and polyisocyanate (B) components are designed in compliance with the requirements of technical specifications TU V.2.7-24.1-13803953-017-2011 «*Techno-PUR* Polyurethane System.» Their pilot batch has been produced at the *Techno-Resource* Engineering Center of the NAS of Ukraine, poured into sealed containers and supplied to construction sites for mixing fluid injectable polyurethane reactive composites. The laboratory and industrial tests have showed that the pilot batch of «A» component is as good as its foreign analogues produced by *Bayer*, *Webac*, *Tech-Kahn*, *MC-Bauchemie* (Germany), *Alfa Systems* (Poland), and others by both qualitative and engineering parameters.

4. APPLICATION OF POLYURETHANE AND URETHANE FOAM INJECTABLE COMPOSITES AT CONSTRUCTION SITES

The *Techno-Resource* Engineering Center of the NAS of Ukraine has used the polyol (A) and polyisocyanate (B) components at sites of the Ministry of Regional development of Ukraine and *Ukrvodenergo* for mixing fluid polyurethane materials to be injected into concrete and reinforced concrete structures for their repair and consolidation. The polyurethane and urethane foam injectable materials and technologies for their practical application have been tested on concrete and reinforced concrete sewer collectors of *Lvivvokokanal* municipal utilities operator (Fig. 7); dams and turbine pits of Tashlyk HEPS (Mykolaiv Oblast) (Fig. 8) and the Dniester HEPS (Chernivtsi Oblast); a reinforced concrete retaining wall of *the Ukrainian House* in Kyiv; chimneys of *Zhytomyrteplokomunenergo* municipal utilities operator, etc.

Fig. 5. The reactor of pilot plant for production of «A» polyol components of polyurethane injectable materials

The application of injection technology to the concrete dam structures of Tashlyk HEPS (Fig. 9) has resulted in removal of leakage and seepage of water on a total area of 10 000 m^2. The injection of fluid polyurethane composites under a pressure of 50—150 atm through lead holes drilled in the concrete matrix into the deep cracks of damaged concrete dam is showed in Fig. 10.

On the Dniester HEPS (Novodnistrovsk, Chernivtsi Oblast), water infiltration through the con-

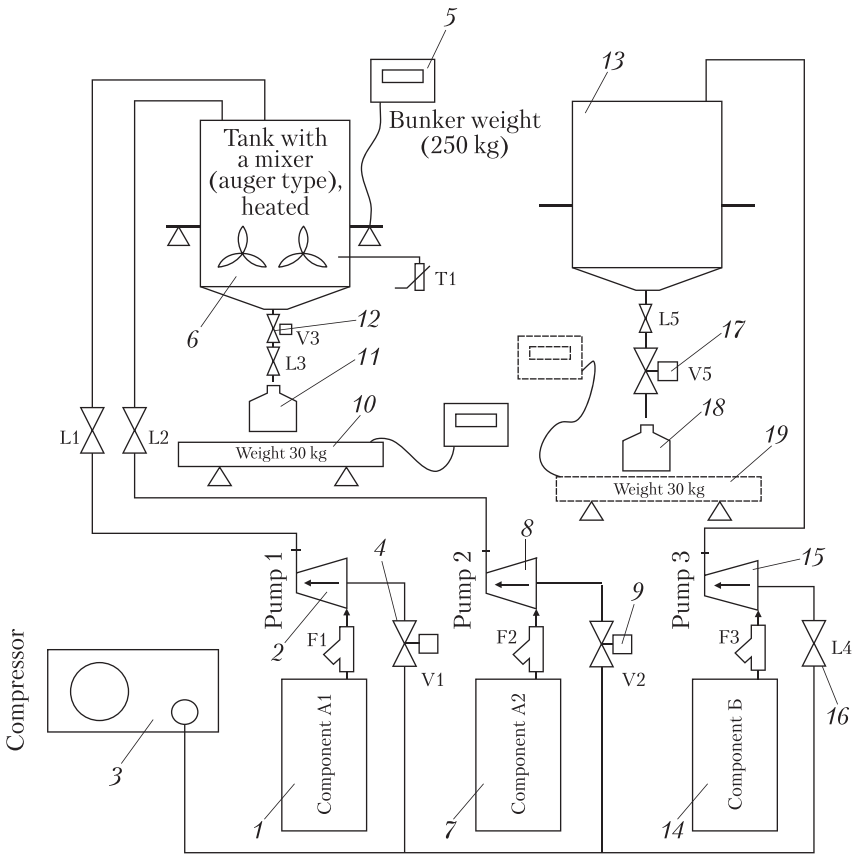

Fig. 6. Flowsheet of pilot production of «A» and «B» components of polyurethane injectable composites

Fig. 7. Repair of sewer collector on Horodotska St., in Lviv, using injection technology. Concrete corrosion (right)

Fig. 8. General view of Tashlyk HEPS (Pivdennoukrainsk, Mykolaiv Oblast)

crete pit of turbine room has been removed (Fig. 10) using the same polyurethane injectable materials (both foam and non-foaming) and technologies as at the Tashlyk HEPS.

CONCLUSIONS

Within the R&D projects of the NAS of Ukraine, fluid polyurethane and urethane foam injectable materials highly competitive with their foreign analogues have been designed, produced, and tested. A technique for their use to consolidate and to rehabilitate damaged cracked concrete and reinforced concrete structures has been elaborated and implemented. A mobile complex for troubleshooting and repair has been designed, produced, and implemented. The preparation and application of «A» and «B» components of injectable polyurethane and urethane foam materials have been elaborated and implemented in production environment. The concrete and reinforced concrete structures of *Lvivvodokanal,* the Tashlyk HEPS, and the Dniester HEPS, *the Ukrainian House* (Kyiv), *Zhytomyrteplokomunenergo,* and others have been rehabilitated and strengthened.

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Fig. 9. Injection of polyurethane composites on Tashlyk HEPS

Fig. 10. The reinforced concrete pit of turbine room at the Dniester HEPS repaired using injectable composites to prevent water infiltration

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СТВОРЕННЯ ПОЛІУРЕТАНОВИХ І ПІНОПОЛІУРЕТАНОВИХ ІН'ЄКЦІЙНИХ МАТЕРІАЛІВ, ЇХ ДОСЛІДНО-ПРОМИСЛОВЕ ВИРОБНИЦТВО, РОЗРОБКА І ПРОМИСЛОВЕ ВПРОВАДЖЕННЯ ТЕХНОЛОГІЇ ЗМІЦНЕННЯ І ВІДНОВЛЕННЯ РОБОТОЗДАТНОСТІ ПОШКОДЖЕНИХ БУДІВЕЛЬНИХ КОНСТРУКЦІЙ І СПОРУД

Розроблено поліуретанові й пінополіуретанові плинні ін'єкційні матеріали, що не поступаються зарубіжним аналогам, та технологію зміцнення і відновлення роботоздатності пошкоджених тріщинами бетонних і залізобетонних конструкцій і споруд. Створено нормативно-технічну документацію на ін'єкційні матеріали і технологічні процеси. Розроблено, змонтовано і освоєно на будівельних об'єктах діагностично-відновлювальний комплекс для реалізації зазначених вище технологій. Запроектовано й виготовлено устаткування, розроблено і освоєно технологію дослідно-промислового виробництва компонентів «А» і «Б» поліуретанових ін'єкційних матеріалів. Виготовлено їх дослідно-промислові партії. Відпрацьовано і впроваджено технологічні процеси приготування і застосування компонентів «А» і «Б» ін'єкційних матеріалів у виробничих умовах.

Ключові слова: ін'єкційні матеріали, відновлення роботоздатності, будівельні споруди.

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СОЗДАНИЕ ПОЛИУРЕТАНОВЫХ И ПЕНОПОЛИУРЕТАНОВЫХ ИНЪЕКЦИОННЫХ МАТЕРИАЛОВ, ИХ ОПЫТНО-ПРОМЫШЛЕННОЕ ПРОИЗВОДСТВО, РАЗРАБОТКА И ПРОМЫШЛЕННОЕ ВНЕДРЕНИЕ ТЕХНОЛОГИИ УПРОЧНЕНИЯ И ВОССТАНОВЛЕНИЯ РАБОТОСПОСОБНОСТИ ПОВРЕЖДЕННЫХ СТРОИТЕЛЬНЫХ КОНСТРУКЦИЙ И СООРУЖЕНИЙ

Разработано полиуретановые и пенополиуретановые текучие инъекционные материалы, не уступающие зарубежным аналогам, а также технологию укрепления и восстановления работоспособности поврежденных трещинами бетонных и железобетонных конструкций и сооружений. Создано нормативно-техническую документацию на инъекционные материалы и технологические процессы. Разработано, смонтировано и освоено на строительных объектах диагностико-восстановительный комплекс для реализации указанных выше технологий. Спроектировано и изготовлено оборудование, разработана и освоена технология опытно-промышленного производства компонентов «А» и «Б» полиуретановых инъекционных материалов. Изготовлено их опытно-промышленные партии. Отработаны и внедрены технологические процессы приготовления и применения компонентов «А» и «Б» инъекционных материалов в производственных условиях.

Ключевые слова: инъекционные материалы, восстановление работоспособности, строительные сооружения.

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