Environmental effectiveness assessment of the technology for molding products made of polymer composite materials using a reusable flexible punch

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Abstracts. The use of composite materials in all industries has a negative impact on the environment in general and man in particular. Polymeric binders include hazardous substances, and the auxiliary components used in production are made of non-processed materials. It is possible to reduce the negative impact on the environment by using a new technology using reusable flexible punches.

1. Introduction
Among a wide range of materials that can be attributed to composite materials, polymers are most widely used due to unique characteristics and availability in production. Polymer composite materials (PCM), as the name implies, are based on polymeric materials, however this generalization is too common and includes a very wide range of materials, and the choice of a polymer for a composite depends on operating conditions, strength and economic parameters of the construction, production equipment, etc. Today epoxy and polyester resins are used as binders in most engineering industries [1], due to the range of mechanical, operational, rheological and other characteristics that meet the challenges facing rocket and aviation equipment, as well as in the manufacture of ships, cars and rail transport. Equally important is the direction of engineering companies that develop engineering, and for which it is necessary to ensure efficient and safe production of products from composites [2].

Polymer composite materials based on epoxy and polyester compounds are include components that can have a negative impact on human health and the environment as a whole. Epoxy binders are harmless to humans in the cured state, but in the uncured form are sufficiently strong poisons. The composition of epoxy resins includes phenols and bisphenols, as well as epichlorohydrin [3], which affects the kidneys. Epoxies are dangerous both in direct contact with the skin, and when inhaling fumes.

Polyester resin, in turn, is relatively safe in itself, but hazardous accelerators, thinners and hardeners may be included [4]. Styrene – a good solvent for polymers, is the most dangerous one. Styrene affects the central and peripheral nervous systems, digestive tract, metabolism. Polyester compounds are also dangerous when in direct contact with the skin and when inhaling vapors.

If we consider another component of polymer composite materials, a filler, then it is not completely harmless. Among fillers, glass and carbon fabric are common. Fiberglass is woven from glass fibers with a diameter of 10-15 microns. So thin glass fibers are flexible enough, but it can still break. The
fragility of this diameter glass fibers leads to the large number of debris, easily penetrating the pores of the skin and causing itching. Inhalation of air with glass fibers debris may cause lung irritation. Similar factors are observed when working with carbon fabrics, although carbon fibers are less brittle, but their diameter is less, from 5 to 10 microns. Fragments of fibers are formed during cutting and laying of fabrics in most methods used, and are associated with direct contact with humans.

2. Objects and methods
Among industrial methods for manufacturing PCM products, contact molding, vacuum infusion, autoclave molding, RTM and winding can be distinguished [5]. There are other methods, but they are variations of the methods listed and the advantages and disadvantages described below apply, including. Contact molding process is the almost manual. The point of this method is application of polymer onto a fibrous filler using brushes and rollers [6]. This method does not require any technological equipment, it is quite simple, but the most dangerous for the technologist, because the whole polymerization process takes place in the atmosphere. In addition, products obtained by this method do not differ in high values of mechanical and strength characteristics [7]. To improve the composite characteristics, as well as to reduce the harmful effects, sealed vacuum bags are used. Preform (a set of dry reinforcing fabric layers) is placed into this bag, and then the preform is impregnated with a polymer binder [8]. This method is called vacuum infusion, and combines relative safety, economic efficiency and product quality [9]. The disadvantages of the method include a large complexity and a large amount of waste. The highest product quality can be achieved using autoclaves [10] – closed vessels in which the binder is polymerized at high pressure and temperature (more than 5 atmospheres and 250 °C) [11]. However, an autoclave is a very expensive device, which, among other things, according to safety rules. For example, it cannot be placed in educational institutions. Least-laborious for the technologist is RTM method. When manufacturing products using the RTM method, the technologist only needs to put the cut fabric in a metal mold, then close half the hydraulic press and start the impregnation in automatic mode [12]. This method is also characterized by high environmental friendliness, because the technologist contacts the binder only at the stage of replenishment of sealed containers. The disadvantages of the method include the very high cost of equipment and the limited size of the resulting product. The most technologically advanced method for the production of composites is the winding method, where continuous fiber is applied layer-by-layer to a rotating mandrel. This method combines the low cost of equipment, high productivity and low labor costs. However, this method has two critical drawbacks: low environmental friendliness and the ability to manufacture only rotation parts. A new method for manufacturing composite products using reusable flexible punches stands combines the advantages of vacuum infusion and RTM. In this method, the technologist practically does not contact the polymer compound, while the low complexity and cost of the equipment increases the manufacturability of the production.

3. Results and Discussion
One of the ways to reduce the influence of harmful components on the human body and the environment is by impregnating the filler in closed systems [13]. For example, when using equipment with a reusable elastic punches (Fig. 1).
In such equipment, the components of the binder, resin and hardener, are poured into sealed vessels in advance, and until the curing process the operator does not come into contact with them, which significantly reduces the harm from working with the compound.
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Figure 1. Equipment with reusable elastic punch: 1) countertop, 2) pressure cap with a silicon punch 3) control panel, 4) infrared lamp unit

Also, the use of such equipment reduces the amount of waste in production. In the classical technology for the production of composite structures, auxiliary materials (films, separating fabrics, plastic nets) are used, which cannot be recycled after use (Fig. 2) [14]. Recycling of these materials is impossible, which affects the environment, and with the increase in the use of composites in industry, the amount of such waste also grows, and exponentially, because in the production of one composite product, three types of waste are generated.

Figure 2. Assembled bag for impregnation of samples using vacuum infusion technology

In the manufacture of products using equipment with a reusable elastic punch, two types of auxiliary materials are excluded, and the punch itself is recyclable (Fig. 3).
Figure 3. Assembled bag for impregnation of samples using reusable elastic punch

An important advantage of the equipment with a reusable elastic punch use is the possibility of using thermoplastics as a binder. One of the main drawbacks of PCM with the use of thermosetting binders today is the inability to recycle. The solution is to use thermoplastic polymers, but this is not possible in the case of using traditional production technologies – vacuum infusion, RTM and Light-RTM or autoclave molding. However, equipment using a reusable elastic punches allows this, because the silicone from which the press membrane is made has a melting point of 240 °C, sintering of thermoplastics can be carried out on membrane-vacuum presses. Strictly speaking, membrane-vacuum presses were originally adapted for gluing polymer films onto products. The use of injection or impregnation with a molten thermoplastic binder will not allow full impregnation of the fibrous tissue filler, however, it is possible to use a film binder. The use of such binders will not only allow the processing of composite structures, but also virtually eliminate the contact of the technologist with harmful substances.

4. Conclusion

Despite the sufficient prevalence of PCM in many industries, the manufacturing process of structures made of these materials is dangerous for humans, and it is necessary to develop new technologies that reduce the negative effect not only on the technologist directly involved in the manufacturing process, but also on the environment as a whole. Table 1 shows a conditional comparison of common technologies from which it can be seen that RTM technology and the use of a reusable flexible punches have the most environmental friendliness, with comparative performance and product quality. However, the cost of the product obtained using equipment with a reusable elastic punches is much lower, because lower as the cost of equipment, and molds. This method is quiet useful for modern engineering companies and for education [15].
Table 1. Comparison of common technologies for the production of PCM products

| Technology              | Environmental friendliness | Performance | Product quality | Product cost |
|-------------------------|---------------------------|-------------|-----------------|--------------|
| Contact molding         | Low                       | Low         | Low             | Low          |
| Vacuum infusion         | Average                   | Average     | Average         | Average      |
| Autoclave molding       | Average                   | Average     | Высокое         | High         |
| RTM                     | High                      | High        | Average         | High         |
| Winding                 | Low                       | Average     | Average         | Low          |
| Reusable elastic punch  | High                      | High        | Average         | Average      |

Compared with other methods, the technology using a reusable elastic punch has an average product quality, i.e. the ratio of binder and fiber filler, which directly affects the mechanical characteristics of the product. Yielding to autoclaving, the quality of the products obtained is comparable to the quality of products obtained by the technology of vacuum infusion, RTM and winding. Thus, the use of technology using a reusable elastic punch can significantly reduce the harmful effects on humans and the environment, not inferior in other parameters to other technologies.

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