Electrohydraulic technology for processing triplex glass in the recycling of transport and technological machines

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Abstract. Transport and technological machines are one of the most popular types of equipment used for the development of modern civilization. Unfortunately, their production involves high costs of material, raw materials and energy resources, and their use has a significant negative impact on the environment. The article considers some factors of such an environmentally harmful impact, in particular, related to the process of recycling machines. The importance of solving the problem of resource saving due to the secondary use of structural materials is noted. The current state of technological support for the process of processing triplex automotive glass is analyzed, the disadvantages of existing technologies are noted, and a technology based on the application of electrohydraulic effect is proposed for use. The results of laboratory experimental studies of the effectiveness of this technology in the recycling of automotive triplex glass are presented. The conclusion is made on the feasibility of applying the technology on an industrial scale.

1. Introduction
The modern world fleet of vehicles, including automobile base chassis of transport and technological machines, has more than 800 million units of equipment. According to analysts’ forecasts, over the next 15 years, its number may increase by 3.5 ... 4 times [1]. With the undoubtedly important role of this technology in ensuring the industrial and economic activity of society, self-propelled transport and transport-technological machines (TTM) not only create socio-economic problems in the field of road safety [2], but are also one of the most significant sources of environmentally harmful impact on environment and humans [3,4]. Taking into account the current trend in the development of vehicles and TTM design, there is reason to assume that the emphasis in ensuring their environmental safety, due to the gradual decommissioning of equipment with internal combustion engines and replacing them with electrical energy sources, will shift from the field of combating atmospheric pollution to the energy and resource saving sector, environmentally friendly utilization with widespread use of renovation and recycling of machine components [5]. The implementation of this approach requires the widespread use of environmentally friendly materials in the structures of vehicles and TTM, ensuring their trouble-free secondary use [6,7]. However, not all components of these machines can meet these requirements today. One of them is automotive glass made using the triplex technology. Such glasses, which are classified as safe products, are multilayer, consisting of two glasses glued together with a special film. When such glass is destroyed, its fragments do not fly apart, but remain attached to the film. This increases the safety of products, but complicates the process of obtaining
conditioned cullet. Existing modern glass recycling lines are largely dedicated to the recycling of used glass and old window glass. For processing triplex glass, special technology of two-stage crushing in multi-roll plants is used with subsequent separation and manual sorting [8]. Since when triplex is milled, many small pieces of film are formed, which cannot be completely removed by aspiration and optical sorting, the resulting cullet does not meet the requirements of standards for the amount of impurities [9] and does not find wide reuse. Analysis of the traditional technology of processing triplex glass shows that it is long, expensive and environmentally unsafe, and as a result of processing, cullet of low quality is obtained. The energy consumption for grinding triplex mechanically ranges from 14.8 to 22 kWh/t [10].

The calculations show that with the number of vehicle fleet in Russia about 50 million units and with an average service life of a car of 10 years, the annual need for processing triplex glass can reach 30 thousand tons. Such volumes of processing dictate the need to use more advanced technologies. One of the areas of their creation can be a technology based on the use of the electrohydraulic effect.

2. Task, object, subject and research methods

The electrohydraulic effect (EHE), as a way of transforming electrical energy into mechanical energy, was formulated by L.A. Yutkin in 1950. The essence of EHE is that with a pulsed electric discharge in a liquid between two electrodes, a complex of acting factors arises that can have a different effect on the medium being processed [11]. The objective of the study is to assess the possibility of creating a technology for recycling automotive triplex glass using the existing factors of the electrohydraulic effect. The object of research is a multilayer automotive glass consisting of two glasses firmly fastened together with a polyvinyl butyral film. The subject of research is the process of breaking, crushing and sieving glass into fractions. Research method - experimental studies of the process of destruction of triplex type glass in a specially created laboratory electrohydraulic unit.

3. Results and discussion

A schematic diagram of an electrohydraulic unit created for research is shown in Figure 1.

![Figure 1. Schematic diagram of an electrohydraulic unit.](image)

The acting factors of the electrohydraulic effect include ultra-high hydraulic pressure, fluid movement at high speeds, powerful cavitation processes, infra- and ultrasonic radiation, and mechanical resonance phenomena. In this case, the key factor of the destructive effect is the ultra-high hydraulic pressure in the discharge zone, which is capable of selective destruction of the components of the processed material. In the process of research, a selection of the power of a high-voltage electric discharge was made empirically, providing for the crushing of glass and its separation from the film without destroying it. For experiments, the windshield was divided into fragments. The processed pieces of triplex glass were placed on a classification grid and processed with high-voltage electric
discharges in water, which was filled in the unit. The scheme of organization of the process of crushing triplex glass is shown in Figure 2.

![Figure 2. Scheme of the organization of the process of crushing triplex glass.](image)

Figure 3 shows the process of crushing and delamination of triplex glass by the stages of its electrohydraulic processing.

![Figure 3. Results of glass crushing and delamination by processing stages: a) - the initial state of the glass; b) - the initial stage of cleaning the substrate from glass; c) - an intermediate stage of cleaning the substrate from glass; d) - the second stage of cleaning the substrate from glass; e) - completely cleaned glass substrate; f) - high degree of purity of the triplex glass substrate.](image)
The results of the experiments showed that in the course of electrohydraulic processing of triplex glass, it is possible to combine the processes of crushing, separation of glass from the polymer substrate, washing and classification of cullet. At the same time, there is a high quality of cullet washing and removal of contaminating products. Unlike multi-roll crushing, there are no wear products of grinding elements in fine fractions, and glass dust is not formed during processing. By varying the power of the electric pulse, it is possible to set the size of the resulting glass fraction. Estimated electricity consumption for processing 1 ton of triplex glass is 4...4.5 kW*h. The processing time for one glass weighing 15 kg and an area of 1.31 square meters is 65 seconds. The use of classification grids in the processing allows catching the cleaned cullet of the required fraction (Figure 4).

![Figure 4. Crushed cullet of 6 mm fraction.](image)

4. Conclusion
Experimental studies have shown that the electrohydraulic technology provides effective glass separation from the substrate with a high degree of substrate cleaning. The fractional composition of the resulting material is regulated by the selection of operating modes of the unit and the use of the necessary classification grids. Electricity consumption for processing 1 ton of triplex glass is 4...4.5 kW*h, which is 4...5 times less than the energy consumption for mechanical grinding (from 14.8 to 22 kW-h/t).

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