Assessment of Impact and Ballistic Resistance of Some Types of Organoplastics

Nikoloz Chikhradze¹,², Guram Abashidze¹, Davit Tsverava¹, Sophiko Kvinikadze¹, Lia Kirtadze¹
¹LEPL Grigol Tsulukidze Mining Institute of Georgia, 0186, Tbilisi, Georgia
²Georgian Technical University, 77, Kostava Str, 0160, Tbilisi, Georgia
chikhradze@mining.org.ge

Abstract. The paper represents the results of the experimental determination of impact resistance and the principles of assessing the ballistic resistance of organoplastics. Organoplastics are presented as a composite material consisting of unsaturated polyester resin (matrix) and a reinforcing component of organic origin, mainly aramid fiber. Reinforcing components are fabrics of various weaves, canvases, and discrete fiber. The polyester resin contains an additive that provides biodegradability of the binding component. In the case of using a biodegradable reinforcing component or a mineral-based reinforcing component, the organoplastics will cause minimal damage to the environment after the exploitation period. Experimental data on the impact resistance of the material were obtained on a 3 m high impact coper on the basis of fixing the work of destruction of samples of organoplastics of a certain thickness. The essence of the ballistic stability assessment was to compile a system of differential equations describing the degree of change in kinetic energy when a bullet (fragment) hits the material and the nature of the decrease in the speed of their contact in the barrier. To solve the system of equations, initial data are required: time, bullet velocity, length of the non-working part of the bullet, cross-sectional area, and mass of the bullet (fragment). The solution of the problem determines the degree of decrease in the speed of the bullet (fragment) contact with the barrier. The obtained research results are suitable for protecting the object from the impact and designing light armor protection of vehicles and other means.

1. Introduction
As it is known, organoplastics are obtained based on binders and their reinforcing components of organic origin. As a binder (matrix), epoxy resins and their modifications are more often used. Other resins, particularly polyester, are given less attention, despite the fact that the difference in their basic physical and mechanical characteristics is small, and the cost of polyester resins is 3-4 times cheaper compared to the epoxy. Therefore, it is advisable to accumulate data on organoplastics with a polyester matrix. First of all, such data is desirable to have the ballistic and impact resistance of this material, while the main purpose of the organoplastics is the protection of various objects from shock and ballistic effects.

This article presents the results of obtaining organoplastics based on unsaturated polyester resin and aramid fabric, evaluation of its impact, and ballistic resistance. Ballistic stability is considered from the point of view of a possible application of the developed organoplastics for the protection of vehicles for various purposes.
2. Methodology

Production of samples and their short-term physical and mechanical tests. For fabrication of specimens of organic plastics, as a binder used in unsaturated polyester resin brand BRE 452 Turkey, reinforcing material-aramid fabric with a surface density of Kevlar s800 d-p145 Korean production. The binder content in organoplastics is 20-22 %. The number of monolayers of reinforcing fabric ranged from 20 to 50. Contact method of forming samples (cold-curing). Physical and mechanical tests of the material were carried out according to the following standards: density – according to ISO 1183 (DIN 53 479, ASTM D 792), water absorption – ISO 62 (ASTM D 570), strength and deformation characteristics - according to ISO R 527 (DIN 53 455, DIN 53 457, ASTM D 638 M).

The impact resistance test was performed in two ways: by the impact of a falling load on the sample, for which a 3 m high coper was used (figure 1). The impact resistance criteria: the behavior of the sample when exposed to a load with a certain kinetic energy. As the second method of testing for shock resistance, we used the impact of an explosive wave on a low-carbon steel plate (35×35×3) mm in size, which was protected by organoplastics. The thickness of the layer of organoplastics on the steel sheet was 5 mm. Figure 2 shows a diagram of a special stand equipped for this purpose, and (figure 3) shows a sample placed on the stand and an explosive charge located at a certain distance from it. The mass of the explosive substance and the distance from the sample were determined experimentally. To record the wave formed, an oscilloscope (model Tektronix DPO 2024B) and sensors of type 113B23 (SN21594) with a sensitivity of 74.25 mV/MPa were used. One of the waveforms obtained during the tests is shown in figure 4. The tests were conducted in an underground explosive chamber. The effectiveness of the protective organoplastics layer was judged by reducing the deformation of the steel sheet.

![Figure 1. Impact testing coper](image1)

![Figure 2. Stand for explosive tests](image2)
A rough estimate of the ballistic resistance of three-layer protective panels obtained with the use of organoplastics. The essence of this assessment was to compile a system of differential equations describing the degree of change in kinetic energy when a bullet (fragment) hits the material and the nature of the decrease in the speed of their meeting at the barrier. At the first stage of interaction of the striker with the barrier with an external ceramic layer, we have a system of two equations, the solution of which gives a change in the speed of the bullet in time and the length of the non-working part of the bullet. In the second stage, when the process enters organoplastics, the full system of differential equations consists of six equations: describing the change in time, the depth of penetration into the ceramic layer, the velocity of the bullet, the length change of the bullet which depends on the thickness of the ceramic layer, changing the rear camber and speed change ceramic cone.

In this approximate assessment of the ballistic stability of three-layer panels made with organoplastics, the theoretical studies described in [1-3] were used.
3. Results and discussions
The main short-term physical and mechanical characteristics of the manufactured organoplastics are as follows: density-1.38 g/cm³; water absorption for 90 days-2.06 %; tensile strength-780 MPa; elastic modulus – 24.6 GPA; elongation at tension – 2.8 %; compression strength-166 MPa; bending strength-355 MPa; strength at interlayer shear-25.7 MPa. Mechanical properties are obtained in the direction of the fabric base, at a test temperature of 20±2 °C. The results show that the main short-term characteristics of the material are inferior to the best analogs of this type, especially organoplastics based on epoxy or modified epoxy binder, but it has a fairly high performance. Given this, as well as the large difference (four times) in the cost of epoxy and polyester resins, it makes sense to identify the limits of the proposed organoplastics.

As a result of testing of organoplastics on copra, it was found that when the impact with a kinetic energy of 2 to 8 J/mm² samples have non – penetrating damage, cracks were observed on the front and back surfaces, in some cases delamination. After impact, the samples are left with an area of plastic deformation – a dent. When an impact with this energy of 11 J/mm² there will be formed damage on the material.

When testing the material for the effectiveness of the protective property, first of all, the required amount of explosive (“Power Gel”) and the distance from the steel plate mounted on the stand were experimentally determined. It was found that the plate receives plastic deformation when an explosion of 2 kg of a substance located at a distance of 0.35 m from the plate. The duration of the peak overpressure was 10 μsec ... 30 μsec and the pressure was 5 ... 30 MPa. The plate is bent by an average of 105 mm (Figure 5). Then, under the same conditions, a plate with a protective layer of organoplastics was tested. The plate received a significantly smaller (30 mm) deflection (Figure 6). Here and below the figure shows the appearance (a) and profile (b) of the tested plates.

![Figure 5. General view (a) and profile of the plate (b) without a protective layer](image-url)
In order to find out the possibility of predicting the ballistic stability of the protective layer, an example was considered: a three-layer barrier has an outer ceramic layer of B₄C, an intermediate layer of organoplastics, and a back, titanium layer. The barrier is affected by an armor-piercing bullet weighing 5.38 g and 28.5 mm long. Main characteristics of the ceramic layer: density 2.4 g/cm³, thickness 12 mm. Organic plastics: surface density of 5.5 kg/m². Titanium layer: density 4.4 g/cm³. Another data for calculating the decrease in the speed of the bullet meeting \( V_b \) in the barrier over time \( (\tau) \), according to the above method, are borrowed from the reference literature. The graph below (Figure 7.) shows a decrease in the speed of the bullet meets the barrier in the considered version of the barrier device.

**Figure 6.** General view (a) and profile of the plate (b) with a protective layer

**Figure 7.** \( V_b \) vs \( \tau \) graph in the presence of a three-layer barrier with a middle organoplastics layer

4. **Conclusions**

1. Organoplastics based on polyester resin and aramid fabric reinforcing components were obtained. Its main physical and mechanical characteristics are determined. According to these characteristics, the material is not much inferior to the best modern organoplastics based on epoxy resins.

2. The impact resistance test of the proposed organoplastics using the falling load method showed that at shock energy of up to 11 J/mm², the material does not receive damage which will be through. During the explosive load, a steel sheet protected by organoplastics receives 60-65 % less plastic deformation compared to the deformation of an unprotected sheet.
3. It is suggested that the method of predicting the ballistic stability of panels containing organoplastics can be used by drawing up differential equations based on the laws of conservation of mass, momentum, and energy and solving them.

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