Prospects for the use of composite and polymer materials in transport construction

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Abstract. The article discusses the prospects for the use of road construction elements made of composite and polymer materials. Currently, the main materials used in the production of road infrastructure elements are metal, concrete and plastic. The use of modern polymeric materials will eliminate the disadvantages of the materials used with the same advantages. The study considers the possibility of replacing steel energy-absorbing elements of frontal road barriers with energy-absorbing elements, which are made of a polymer material based on ultra-high molecular weight polyethylene (UHMWPE). The comparison was carried out on the basis of digital modeling of a vehicle collision with a frontal road barrier according to the energy absorption criterion using the LS-Dyna nonlinear dynamics software package. The developed digital models are validated by bench and field tests. Based on the results of the virtual tests, the dimensions of the energy-absorbing elements of the polymer structure of the frontal road fence were selected, which in their properties is not inferior to the used metal analogue. The results obtained prove the prospects of using modern composite and polymer materials in road safety systems.

1. Introduction.

Currently, metal, concrete, reinforced concrete and plastics are used for the production of road safety systems. At the same time, the overwhelming majority of barrier and cable retaining road fences are made of steel, parapet and curb fences are made of concrete or reinforced concrete, and dividers, signal posts and water barriers are mainly made of plastics (Figure 1) [1].

The disadvantages of metal fences include high cost, expensive repairs, rather complicated installation (specialized equipment is required), as well as corrosion, especially in aggressive environments.

Concrete and reinforced concrete fences have a high holding capacity when vehicles run over them, which does not allow vehicles to drive into the oncoming lane, however, installation and replacement of concrete and reinforced concrete barrier-type fences is carried out only with the help of special equipment. A significant drawback is the fact that in a collision with a vehicle, concrete and reinforced concrete fences practically do not deform and do not protect a person from injury and damage.

One of the most important advantages of plastic elements of road infrastructure (ERI) is the low cost. Another advantage of plastic products is the ability to manufacture products of almost any shape, size and color. Plastic structures are often placed on a temporary basis to mark repairs and hazardous areas. The disadvantage of plastic is the inability to provide a high holding capacity due to its low mechanical
strength, therefore, when a collision occurs, the vehicle is able to leave the roadway or drive into the oncoming lane. Plastic products are also very sensitive to low temperatures and it is quite easy to leave mechanical damage on such structures (scratches, cuts, tears etc.).

Currently, the volume of use of composite and polymer materials for the production of ERI is growing every year. Improving road safety criteria requires the use of new materials with predetermined properties in structures. Materials with ultra-high strength, hardness, heat resistance, corrosion resistance, chemical inertness, UV resistance and other properties and their combination are required.

The main advantages of composite and polymer materials over traditional ones (metals, concrete, reinforced concrete, plastic) are:

1) a unique combination of properties uncharacteristic for other materials (strength, deformation, impact, elasticity, temperature, rheological, adhesive, electrical, frictional, heat-conducting etc.);
2) the ability to control the properties of composite and polymer materials by changing the properties of the matrix and binders or the use of special additives;
3) preservation, when changing the structure and properties of the low density of the material, and, consequently, the weight of the entire structure, as well as the possibility of almost 100% recycling.

One of the main disadvantages of composite and polymer materials is their high cost at the stage of technology creation, production of experimental products and its certification. In mass production, the use of advanced composite and polymer materials will reduce the weight of ERI structures and their cost without reducing consumer characteristics.

The growing range of materials used in the field of ERI production requires the development of testing both samples of materials (in order to obtain strength and mechanical characteristics) and parts of ERI structures (to obtain the given and consumer characteristics). A correctly developed and applied test method will allow validating the digital model at a high level, and, as a result, will lead to a verified virtual experiment.

2. Materials and equipment.
This study compares the metal structure of the frontal road fence (Figure 2) and the proposed structure made of polymer material. [2]. UHMWPE was considered as the material of the energy absorbing element. Determination of mechanical and strength characteristics was carried out using a Tira Test
2300 testing machine with a maximum machine force of 100 kN and a maximum loading speed of 1000 mm/min. Tensile loading was carried out at different loading rates (20-500 mm/min). As a result of the experiment, the value of the elongation of the sample was recorded, as well as the value of the force of resistance to elongation of the sample. According to the test results, mechanical and strength characteristics were determined, which is reflected in [3]. The rest of the characteristics were determined from studies [4, 5].

Having determined the main mechanical characteristics of UHMWPE, it was decided to develop a fence structure with an energy-absorbing element in the form of a cylinder (Figure 3).

To determine the magnitude of the energy absorption of such an element, compression tests were carried out. The tests were carried out on a Tira Test 2300 testing machine with a maximum machine force of 100 kN and a maximum loading speed of 1000 mm/min. The test scheme is shown in Figure 4.
Figure 4. Compression test scheme for a sample of an energy-absorbing UHMWPE element

As a result of a full-scale experiment, a diagram of dependence $P=f(u)$ of the effort on the movement of the active traverse of the testing machine was built (Figure 5). According to the results of experimental data on the diagram, the value of energy absorption was $U_{\text{exp}} = 0,326$ kJ. The sample after testing is shown in Figure 6.

Figure 5. The graph of the dependence of the resistance to compression on the traverse movement

Figure 6. Sample of energy absorbing element at the moment of full compression

Figure 7. Graph of dependence of forces on displacements of a compressive element
Analyzing the appearance of the sample after testing, it was noted that after three days the residual deformations were less than 10%, from which it can be concluded that with such a design of the energy-absorbing UHMWPE element can be reused after significant deformations, in contrast to steel energy-absorbing elements.

3. Model and methods.
Virtual tests were carried out on the basis of the finite element method (FEM) using a multipurpose software package Ls-Dyna (Licence SIC Research Institute of mechanical and quality problems №2034, under contract №12/12/16 from 12 December 2016) [6-9]. As a result of the virtual experiment, a graph $P=f(u)$ of the dependence of the force on the movement of the compression plate was built, which was compared with an identical graph obtained in the course of a full-scale experiment (Figure 7). The compression process of a sample of an energy-absorbing UHMWPE element is shown in Figure 8.

![Figure 8. The process of compression of the FE model of a sample of an energy-absorbing element made of UHMWPE](image)

According to the results of the virtual experiment, the energy absorption of the UHMWPE sample was $U_{FE} = 0,335 \text{ kJ}$.

Let's consider one of the possible design options for the sections of energy-absorbing elements in the form of UHMWPE cylinders (Figure 9).
To compare the energy absorbing capacity, a model of energy absorbing elements in the form of metal honeycomb sections was also built (Figure 10).

To determine the value of the energy absorbing capacity, a virtual test model for the compression of the energy absorbing elements in the assembly was built. The test scheme is shown in Figure 11. The loading process was realized by means of an absolutely rigid plate, moving at a speed of 20 mm/min.

4. Results
According to the results of virtual tests, the values of energy absorption capacity were obtained. Energy absorption diagrams are shown in Figure 12.
Table 1 shows the range of values of energy absorption by UHMWPE sections with an outer diameter of 90 mm during loading, and the mass of the structure. For comparison, Table 2 shows similar indicators for steel elements.

| Parameter          | Thickness 8mm | Thickness 9mm | Thickness 10mm | Thickness 11mm |
|--------------------|---------------|---------------|----------------|----------------|
| Energy absorption  | 6,0*10^7 J    | 6,42*10^7 J   | 7,73*10^7 J    | 9,24*10^7 J    |
| Weight             | 37,99 kg      | 42,49 kg      | 46,92 kg       | 51,32 kg       |

Table 2. Energy absorption and weight of the steel structure

| Parameter                        | Weight | Energy absorption |
|----------------------------------|--------|-------------------|
| Honeycomb made of steel with a wall thickness of 2 mm | 64,72 kg | 6,52*10^7 J |

5. Conclusions.
Based on the results obtained, it can be preliminarily concluded that UHMWPE can be used as a material for energy-absorbing structural elements. With an outer diameter of 90 mm and thicknesses from 8 mm to 11 mm, the closest energy absorption to steel is achieved.

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