ANALYSIS OF CARBON PLASTICS DESTRUCTION CAUSES BASED ON EPOXY BINDING

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ABSTRACT
Various products often contain defects. The reasons for their formation can be a material manufacturing technology, and the defects manifested during a product operation. The analysis of material destruction causes due to defects is an urgent task, the solution of which will prevent a product premature failure. The paper considers the reasons for an undesirable manifestation of a sudden catastrophic destruction of a product made of carbon plastic obtained on the basis of T-700 carbon fiber and a soluble epoxy binder. Microstructural studies of cross sections of carbon plastic product in the adjacent area of failure revealed the main types of defects:

- the pores, which are oblong defects with a considerably greater length along fiber layers;

- long narrow voids-splits at the interface of the phases "carbon fiber-matrix".

The method of differential scanning calorimetry showed an insufficient degree of epoxy resin curing. Thus, the sample is characterized by the additional curing of the binder in the temperature range of 55-96 °C with the thermal effect of 5.3 J/g and the temperature maximum of 90.5 °C. The mechanism of plastic carbon studied sample fracture is proposed, which consists in longitudinal cracking of the matrix due to the low degree of the epoxy matrix structuring, weak adhesion between fibers and a matrix, the presence of various voids and pores, as well as in non-ideal stacking of carbon fibers. Since there is a misorientation of the carbon fibers, the longitudinal crack can also cut them, thus this defect area will be a stress concentrator. A portion of the cut fibers can peel off, resulting in the development of a secondary longitudinal crack, which in its turn will lead to the appearance of the following cut fibers. The result of this mechanism is the destruction of the material in two parts with the development of a rupture site torn surface.

Keywords: carbon plastic defects, mechanical failure, microphotographs, differential scanning calorimetry, glass transition temperature.

INTRODUCTION
Composites are used widely for the manufacture of parts and components in the automotive and agricultural machinery industries. The main advantages of composites for these industries: corrosion resistance, increased resistance to mechanical damage, sound absorption, economy. Due to the use of light composites, the total weight of automotive and agricultural machinery is reduced, which means that fuel is saved during its use [1-7].

Composite materials based on polymer binders reinforced with carbon fibers - carbon plastic, possessing a unique complex of technically valuable properties, such as: high specific strength, low elongation at deformation, high thermal stability and electrical conductivity. Under the conditions of operation, the products and the structures made from polymer composite materials undergo various types of mechanical stresses, which can lead to the change in their structure and, accordingly, their operability [8-10]. In order to evaluate the performance characteristics under the conditions of permanent mechanical action, it is
necessary to study the defects that arise in the process of plastic carbon product molding based on an epoxy binder.

**METHODS**

The study was carried out on destroyed product samples made of carbon plastic based on T-700 carbon fiber and a soluble epoxy binder. In order to obtain the prepregs based on a solvent binder, carbon fiber impregnation technology was used, followed by the removal of the solvent through the drying method. The resulting prepreg was laid out for the molding under a press.

Differential scanning calorimetry (DSC) was recorded using a differential scanning calorimeter "Netzsch DSK 204 F1 Phoenix". The DSC analysis was carried out in a dynamic heating / cooling regime at the rate of 10 °C / min in an argon flow at the rate of 50 cm³ / min.

**RESULTS AND DISCUSSION**

It is known that the cause of mechanical failure is the action of external forces and when the yield stress is exceeded, a product can be broken into parts. An example of mechanical fracture due to the application of forces created by a shock load can be illustrated on Fig. 1.

![Fig. 1. Microphotograph of the region of scrap of an article of carbon fiber reinforced plastic obtained as a result of mechanical action](image)

Fig. 1 shows that the surface of the material rupture is torn and jagged with sharp edges. It is also possible to characterize a fracture as a step-like one with a visible lateral stratification of a matrix from a fiber and the separation of single fibers. Possible stress concentrates in this sample may be represented by voids, pores, reducing the strength characteristics and the plasticity of products. Due to these defects presence during the mechanical action, the article under study was destroyed in two parts.

In order to determine the presence of defects in a product, as well as to assess the nature of interaction between a polymer matrix and a filler, the end faces of carbon plastic samples were obtained by the use of sample preparation traditional method for materialography. The following equipment used: polishing machine METASERV 250, electric drive nozzle Vektor, compressor ECU 200, abrasive cutting machine METACUT 251.

The defects were examined and evaluated on cross sections with respect to the direction of carbon fibers. The photographs of the microstructure were made using motorized metallographic complex Thixomet. Fig. 2 demonstrates the view of carbon plastic section with the thickness of 1.5 mm.
The analysis of Fig. 2 showed that two types of basic defects are observed in the structure of the shaped carbon fiber product: these are pores and delamination at the boundary of the "carbon fiber-matrix" phases, and it should be noted that the split interface has a great influence on the development of defects.

In [11] they showed microstructural studies of carbon plastic split surface formed during the operation of a product. The conducted studies revealed that the destruction of carbon plastic takes place along the fiber boundary layer of the matrix with the development of a stepwise type of fracture. Torsions are formed and its plastic deformation is observed in the matrix between the fibers.

It is known that stress concentration is often caused by notches, cracks or sharp angles, as well as by large defects such as pores.

Using microphotographs of carbon plastic section products in the adjacent fracture region (Fig. 3), obtained by a microscope, a qualitative assessment of the main types of defects was carried out.
Fig. 3 demonstrates the pores in the samples of the material under study. These pores are oblong defects that have a considerably greater length along the fiber layers. Thus, the size of the largest pore found (Figure 3a) is 458 µm long and 168 µm wide. In the studied sections of carbon plastic, the pores appear in different amounts, and there are also the pores with a multidirectional shape (Fig. 3b) and there are microdotal depressions near the carbon fiber filaments.

[12] shows that the pores lead to a significant decrease of the compressive strength. Only 1 and 4% of the pores lead to compressive strength reduction by 18% and 36%, respectively. Such a strong reduction in strength is conditioned by the longitudinal cracking of the composite material. When carbon plastic is destroyed during compression, the kink usually appears, that is, the destruction leads to the appearance of a shear band. The compressive strength values are proportional to shear strength, strongly dependent on porosity and significantly lower than the shear modulus of the composite. This is due to the destruction mechanism of carbon plastic by cracking.

On Fig. 2, in addition to the pores of large dimensions, long narrow void-splits are observed at the "carbon fiber-matrix" interface. The development of these defects is associated with poor adhesion between the carbon fibers and carbon plastic matrix. Thus, under mechanical stress, carbon fiber plastic can be split, and a stepwise fracture can take place with a predominantly delaminating matrix from the fiber. This type of failure is well illustrated by the destruction of the sample into two parts, shown on Fig. 1.

Thus, analyzing the obtained data, it can be assumed that the fracture mechanism of the sample under study is the longitudinal cracking of the matrix due to a weak adhesion between fibers and a matrix, the presence of various voids and pores, as well as non-ideal stacking of carbon fibers. Since there is a misorientation of the carbon fibers, the longitudinal crack can also cut them, thus this defect area will be a stress concentrator. A portion of the cut fibers can peel off, resulting in the development of a secondary longitudinal crack, which in its turn will lead to the appearance of the following cut fibers. The result of this mechanism is the destruction of the material in two parts with the development of a rupture site torn surface.

Since the fibers are surrounded by a matrix, the redistribution between a matrix and a fiber is crucial. The main load is carried by the fibers, so many requirements are imposed on the mechanical properties of the matrix. In order to avoid premature cracking of the matrix, its deformation during destruction should be sufficiently large. Mechanical properties should not be changed under the influence of the environment (humidity, temperature, radiation). Deformation at failure can be increased by crosslink density reduction, but this will lead to the reduction of rigidity. Since composites based on a thermal reactive matrix are viscoelastic and do not exhibit plasticity, this leads to the limitation of the allowable stress.

It was shown in [12] that when the temperature of carbon plastic increases from 20 to 90 °C, the strength decreases gradually, and in the glass transition region of the matrix a transition occurs from the fracture due to the cracking with the development of a kink to failure due to the loss of fiber stability. When samples are tested above the glass transition temperature of the matrix, the fracture band is perpendicular to the fiber axis. In the glass transition temperature range of the matrix, they change the fracture mechanism and, correspondingly, the orientation angle of the fracture zone. Above the glass transition temperature, the fracture zone becomes perpendicular to the fibers.

Since the strength of carbon plastic is greatly reduced at the glass transition temperature of the matrix, the study of the glass transition temperature of the epoxy matrix was the next urgent task.

The methods of thermal analysis are widely used to analyze the causes of destruction. Differential scanning calorimetry is a common method of analysis, because it helps to determine the main characteristics of a polymer, and the use of this method to thermal reactive resins allows us to assess the
degree of structuring. Using this method, the sample taken from the material fracture region was analyzed, since insufficient dense crosslinking may result from the destruction of the product, which leads to a sharp decrease of mechanical properties.

![Graph](image_url)

**Fig. 4.** DSC – thermal graphs of the sample of the exploded broken sample of the carbon fiber reinforced plastic product

The analysis of Fig. 4 showed that the sample is characterized by the additional curing of the binder in the temperature range of 55-96 °C with a thermal effect of 5.3 J/g and the maximum at the temperature of 90.5 °C.

It is known that an insufficient degree of a micromatrix dispersion medium curing in a thermal setting polymer promotes its plastic rearrangement under the influence of an external mechanical or thermal load. This fact explains a weak interaction between the particles, which under the action of loading are able to move in a micromatrix [9]. In a molded sample, the phase separation of the matrix continues during the operation of the article, leading to an uncontrolled creep, shrinkage, warpage, and reduced crack resistance. Therefore, a sample can be characterized by brittle fracture during the operation of a product.

In the studied sample of carbon plastic article, the size of the plastic zone is limited by the distance between neighboring fibers, so carbon plastic fracture viscosity is determined not by the size of the plasticity zone in a matrix, but by the distance between fibers. In the case of longitudinal cracking, the matrix and the interface of the "carbon-matrix" phase separation are destroyed.

Thus, the destruction of the epoxy resin and a weak interaction between carbon-matrix interface result in the destruction of a carbon fiber product.

**CONCLUSIONS**

1. They studied the reasons for the destruction of a composite product obtained on the basis of T-700 carbon fiber and a soluble epoxy binder.

2. They analyzed the region of carbon plastic product break, obtained due to mechanical failure and the application of forces created by the impact load.
3. They performed the microstructural studies of transverse sections of the carbon plastic product in the adjacent area of failure and a qualitative assessment of the main types of defects.

4. Defects were detected in the samples of the material under study: pores, which are oblong defects with a considerably greater length along the fiber layers; long narrow voids-splits at the interface of "carbon-matrix" phase separation.

5. The method of differential scanning calorimetry shows an insufficient cure rate of epoxy resin. Thus, the sample is characterized by the additional curing of the binder in the temperature range of 55-96 °C with the thermal effect of 5.3 J/g and the maximum at the temperature of 90.5 °C.

6. The destruction mechanism of carbon plastic sample is proposed, represented by the longitudinal cracking of the matrix.

7. They revealed the reasons for the destruction of carbon plastic sample, such as an insufficient cure of epoxy resin, a weak adhesion between carbon fiber and matrix, the presence of various voids and pores, as well as non-ideal packing of carbon fibers.

**SUMMARY**

The destruction mechanism of the carbon plastic sample under study is proposed, consisting of longitudinal cracking of the matrix due to the low degree of epoxy matrix structuring, a weak adhesion between fibers and the matrix, the presence of various voids and pores, and also by non-ideal stacking of carbon fibers.

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**REFERENCES**


