POSSIBILITIES OF A NONDESTRUCTIVE ONE-PARAMETER
METHOD OF CHECKING THE STRENGTH OF ANISOTROPIC
GLASS-REINFORCED PLASTICS IN UNIAXIAL COMPRESSION

E. K. Ashkenazi, A. K. Sborovskii,
M. V. Gershberg, R. S. Raikhel'gauz,
and M. G. Kapustin

A nondestructive method of checking the strength of glass-reinforced plastics (GRP) in
finished products is proposed. This method is based on the correlation, investigated by
the authors, between the modulus of elasticity and the compressive strength determined
by a standard method. Various orientations in the plane of reinforcement of glass-rein-
forced plastics with different ratios of the orthogonally arranged fibers are investigated.
It is proposed to determine the modulus of elasticity from the propagation velocity of an
ultrasonic pulse measured under conditions of one-sided access to the surface of the
product.

In the process of thousands of years of natural selection the reinforcement principle has evolved as
a means of optimizing the resistance of biological tissues to "operational" loads. In wood and bone the
reinforcing elements follow the trajectories of the principal stresses. The dimensions of the reinforcing
elements are relatively small, and their uniform distribution makes it possible to regard the material as
a quasihomogeneous continuous anisotropic medium with orthogonal or transverse symmetry of the me-
chanical properties.

A similar principle is applied in structural glass-reinforced plastics. The material is created at
the same time as the structure, and the properties strongly depend on the nature of the reinforcement and
on the fabrication technology. This makes the quality control of glass-reinforced plastic articles particu-
larly important.

Modern methods of quality control include flaw detection [1, 2], nonsampling stiffness (elasticity)
control [3, 4], and nondestructive strength control.

For anisotropic glass-reinforced plastics it is necessary to determine not just one strength char-
acteristic of the material, but a whole series of such characteristics [5]. These are used to estimate the
strength of the critical element of the structure, which is frequently in a state of combined stress. To
determine precisely which element is the critical one and the state of stress that exists in it requires a
preliminary analysis of the operational data and the results of full-scale tests. The task is complicated
by the polymorphism of glass-reinforced plastic fracture, which depends strongly on the fabrication tech-
nology and on the design of the individual elements of the structure.

The problem of nondestructive estimation of the strength of an article can be conventionally divided
into two interrelated problems: the nondestructive estimation of the strength characteristics of the mate-
rial and the nondestructive estimation of the operational strength of the structure. This article is devoted
to the first of these problems.

The object of the nondestructive estimation of the mechanical properties of a glass-reinforced plas-
tic without taking samples and without loading the structure is to obtain starting data for solving the sec-
ond problem.

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The development of a nondestructive method of checking the strength of a glass-reinforced plastic can be based on various models of the material. Glass-reinforced plastics are multicomponent heterogeneous systems incorporating solid, liquid, and gas phases. The presence of liquid and gas phases is associated with the porosity and microporosity of the material. The greatest strength is possessed by glass-reinforced plastics with a disperse quasihomogeneous structure. They are characterized by very low porosity and consist chiefly of solid phase; they are therefore frequently considered as two-component media. The third model refers glass-reinforced plastics to anisotropic quasihomogeneous media.

Nondestructive methods of estimating the strength, based on the treatment of a glass-reinforced plastic as a multicomponent medium, were investigated in [1, 6, 7]. These methods presuppose the experimental measurement of two or more parameters of the material for judging its strength and may be used for controlling the quality of articles of the same type, where great accuracy is required because of the small ranges of variation of the quantity evaluated.

The proposed one-parameter method, based on the treatment of a glass-reinforced plastic as a continuous elastic anisotropic medium, is intended for obtaining a rough estimate of the strength of a material element forming part of the structure from the results of measuring a single parameter.

It should be noted that to a considerable extent the approximity of the strength estimates obtained is due to the imperfections of the destructive methods of conducting control tests on specimens of the material. It is well known that the question of "destructive" methods of determining the strength characteristics of glass-reinforced plastics is still a subject of debate. This applies especially to compression tests in which the polymorphism of the physical-fracture pattern of glass-reinforced plastics and brittle materials generally [8] is more strongly expressed than in other types of testing. The question of the comparability of the results of different destructive methods of testing glass-reinforced plastics and their relation with the strength of the structure lies outside the scope of this article.

A characteristic feature of glass-reinforced plastics is the variability of their composition and structure; these strongly depend on the fabrication technology, as a result of which the mechanical properties are statistically random quantities. In solid-state physics functional relations between different physical properties are derived for certain idealized homogeneous media. The objective existence of these functional physical relations for a real multicomponent heterogeneous material with considerable variability of the properties is realized in the form of correlations between the corresponding characteristics. Pair correlation [9, 10] makes it possible to verify the existence of a relation between two random quantities (physical characteristics) and to obtain a quantitative estimate of the closeness of the relationship. The choice of characteristics is based on physical considerations.

There are no universal and absolutely accurate methods of nondestructively testing the strength of materials. Some methods are suitable for metals, others for nonmetallic composites. Each method is based on physical considerations that make it possible to assume the existence of a relationship between the strength of the material and other physical properties.

As shown, for example, in [11] for an idealized, absolutely homogeneous material, an analysis of the simplest diatomic model leads to a linear relation between the tensile strength $\sigma_u$ and the modulus of elasticity $E$:

$$\sigma_u = BE.$$  \hspace{1cm} (1)

For real materials B is always less than 0.1. For anisotropic materials the elasticity and strength characteristics correspond to tensors of the same order and with the same physical dimensionality of the components [5, 12], which makes it possible to regard the elasticity characteristic as the most suitable quantity for developing a nondestructive method of testing the strength of anisotropic glass-reinforced plastics.

For structural steels of different grades the quantity B in Eq. (1) fluctuates within very broad limits (from 0.002 to 0.01), the modulus E remaining practically constant. It is well known that for metal alloys the strength varies with the percentage content of the components, whereas the moduli of elasticity show little change. Thus, for metals there is no reason to expect Eq. (1) to be realized in the form of a correlation between $\sigma_u$ and $E$.

Such nonmetallic heterogeneous brittle materials as concrete [13] and some rocks [14] give a fairly close correlation between the elasticity and strength in compression. Thus, in [14] a stable correlation between the compressive strength and modulus of elasticity was obtained for apatite–nepheline ores. The correlation coefficient was $r = 0.87$ with a confidence interval (reliability 0.95) equal to 0.62–0.95.