EFFECT OF CERTAIN TECHNICAL AND GEOMETRIC FACTORS ON THE PROPERTIES OF GLASS-REINFORCED PLASTICS

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Experimental data are used as the basis for a discussion of some of the technical factors affecting the strength of filament-wound glass-reinforced plastics (GRP): winding speed, tension on the glass, life of resin. A relationship between the strength of GRP and these factors is demonstrated. The effect of the thickness and diameter of the test piece on the tensile strength of GRP material is examined.

One of the factors affecting the properties of filament-wound glass reinforced plastic (GRP) is the winding speed. It is believed [1, 2] that the winding speed has an indirect influence on the strength: the higher the winding speed, the less the amount of resin deposited on the glass reinforcement and vice versa, since the dwell time of the strands in the resin bath varies with the winding speed.

We have carried out experiments to verify this assumption and establish a relationship between the linear winding speed and the percentage ratio of reinforcement and resin.

No. 10 glass yarn (Soviet standard GOST 8325-61), made from alumoboro-silicate glass of nonalkaline composition sized with "paraffin emulsion," was wound onto a cylindrical mandrel, outside diameter 0.33 m, to form annular specimens at linear winding speeds from 0.1 to 1.25 m/sec, i.e., over a quite broad range of speeds. The tension on the yarn was constant at 0.5 N, the temperature of the EFB-4 resin in the resin bath was kept constant within the range 80 ± 5 °C. Not less than five specimens were obtained at each winding speed, after which the resin content by weight was determined.

The results of the measurements, plotted as winding speed versus resin content (Fig. 1) showed that, other things being equal, an increase or decrease in linear winding speed (v) has almost no effect on the amount of resin deposited on the glass reinforcement, and, consequently, should not affect the strength of the GRP. It may be assumed that at lower speeds the depth of impregnation, i.e., the quality, will be somewhat better. Therefore the winding speed should be selected so as to ensure that the strands run smoothly off the bobbins.

Another important factor is the tension on the glass. Some authors consider [2] that the glass should be pretensioned, but do not indicate to what extent. Others are of the opinion that the strands should not be tensioned at all, but merely straightened. Moreover, the tension at the beginning and end of winding may vary.

So far, we have no criterion for determining the tension on the glass. Therefore it was decided to carry out an experiment to determine the effect of tension on the percentage of resin deposited on the glass. As our criterion we took the amount of resin in percent and the effect of this factor on the strength of the GRP.

The breaking load for dry glass yarn No. 10 (GOST 8325-61) is 48.6-54.4 N. It would appear that in the winding process the yarn could be loaded up to failure, but even at a load of 14.5 N the yarn becomes virtually unusable, since it becomes teased and worn and finally the winding process is halted. Moreover, the penetration of resin between the individual filaments deteriorates, which reduces the amount of resin in the strand and leads to a reduction in the strength of the GRP. Conversely, at lower loads the amount of resin coating the filaments increases, which also leads to a reduction in the strength of the GRP.

In order to investigate this question we designed an experiment to determine the relationship between the tension on the glass and the degree of impregnation of the yarn.

Glass yarn No. 10 was wound onto the same cylindrical mandrel at different tensions to form annular test specimens. The winding speed and the temperature of the EFB-4 resin in the resin bath remained constant and equal to 0.035 m/sec and 80 ± 5 °C, respectively. The load on the glass was measured before and after winding by means of a dynamometer. Not less than five specimens were tested at each load. Then the resin content by weight of the specimens was determined.

As a result it was found that the relation between the resin content and the degree of loading (straightening) of the yarn is nonlinear (Fig. 2; s is the load per strand) and asymptotically approaches a value corresponding to the minimum amount of resin in the strand, equal to the approximate volume of the gaps between the filaments in the strand and between the strands when laid in a hexagonal pattern.

Thus, we can recommend a tension per strand equal to 2-3 N, i.e., 3.5-5% PB, which will ensure a resin content (by weight) of 18-20% in the GRP, the optimal value for high-strength unidirectional material.
Increasing the size of the product prolongs the winding process; therefore it was considered necessary to investigate the life of EFB-4 resin (the variation of its viscosity with time at the temperatures used in the resin bath). It is known [3] that resins of increased viscosity cannot penetrate between the strands and wet them uniformly; this leads to the formation of thick coatings of resin and makes it difficult to expel the air during impregnation, as a result of which air bubbles are left in the GRP. All this reduces the mechanical strength and a number of other characteristics. The viscosity also depends on temperature.

Therefore the viscosity or flow can be conventionally determined from the time required by a volume of resin equal to $5 \cdot 10^{-5} \text{m}^3$ to flow through an opening at various temperatures.

As a result of our experiments we were able to plot viscosity curves at temperatures of 60, 70, and 80°C (Fig. 3). As may be seen from Fig. 3, the winding process may go on continuously for 6–7 hr, without the change in resin viscosity having much effect on impregnation and winding.

We will determine the effect of the so-called geometric factors—thickness and diameter of the test pieces—on the strength of GRP.

We will first consider the effect of thickness. However, before considering the GRP as a whole, we will take a look at its components.

There are several explanations of the increased strength of glass fibers [4]. It has been suggested that the high strength of the fiber is determined solely by the scale factor. At the same time, some scientists consider that the hardening of the fiber is associated with structural changes that take place in the glass when it is drawn (molecular orientation and chain formation). It appears that in the drawing process the rigid three-dimensional structure of the glass is converted into a chain structure with weak side linkages, or that during the formation of the filaments the threadlike chain skeletons become oriented.

Other studies based on x-ray and electronographic investigations have failed to detect oriented molecular structure in glass fibers. Treating the surface layer of a fiber with hydrofluoric acid hardens it, which indicates the absence of molecular orientation at the fiber surface during drawing.

A comparative study of the physicomechanical properties of solid glass and glass fiber of similar composition has revealed that the structures of the glass and the fiber are identical.

It is known that the chief reason for the loss of strength of brittle solids is defects—weak spots at which, starting from very small strains, microcracks develop. The causes of crack formation are various and depend on the nature of the material as well as on the method of fabrication.

The reduction in the strength of glass as compared with the theoretical strength is chiefly attributable to surface defects (inhomogeneity and microcracks). As compared with solid glass, thin fibers possess high mechanical strength because of the reduction during drawing of the size and number of dangerous surface defects.

Defects and microcracks at the surface of the fiber may be formed during drawing at a temperature close to the upper limit of crystallization, during forming from a structurally inhomogeneous mass, and as a result of the abrasive action of the drawing machinery.

The strength of the glass fiber depends on the chemical composition of the glass and also on the method and conditions of fabrication. The highest strength is obtained for a fiber drawn at high temperature from a molten mass of glass and rapidly cooled. In this case the most homogeneous structure of the melt is fixed in the fiber and the least favorable conditions for the formation of surface defects during drawing are created.

The relationship between the strength of a glass fiber and its diameter is known. When the diameter is increased by a factor of 100 the strength of the fiber falls by a factor of more than 4. A loss of strength is also associated with elongation of the fiber as the result of an increase in the number of surface defects. It should be noted that these relationships hold for fibers of different composition.

In [5] it was concluded that the breaking stress $\sigma_B$ falls with increase in the thickness of the test pieces.