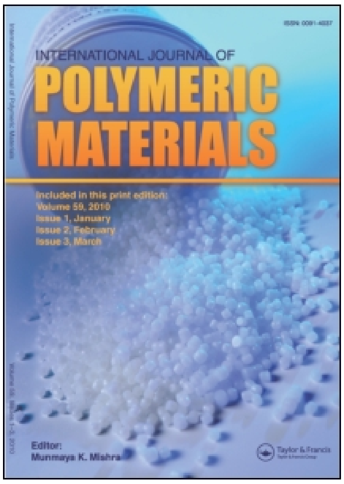

International Journal of Polymeric Materials
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713647664

Application of Spiral Reinforcement for Improving Adhesion Properties of Hybrid Composites

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To cite this Article Freger, G. E. , Karvasarskaya, N. A. and Kestelman, V. N.(1994) 'Application of Spiral Reinforcement for Improving Adhesion Properties of Hybrid Composites', International Journal of Polymeric Materials, 25: 3, 227 — 233

To link to this Article: DOI: 10.1080/00914039408029339

URL: http://dx.doi.org/10.1080/00914039408029339

Intern. J. Polymeric Mater., 1994, Vol. 25, pp. 227–233
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Printed in Malaysia

Application of Spiral Reinforcement for Improving Adhesion Properties of Hybrid Composites

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(Received October 20, 1993)

Good adhesion on the components boundary is of primary importance for the high composite strength. Application of the spatial reinforcement of the material combined with hybridization is a new way of solving this problem and permits to produce spiral reinforced fillers for the composites. Microstructure investigation of these composites and their theoretical and experimental study at different types of loading show changeable character of adhesion in the structure of the given materials. On the basis of the results obtained one could design materials with improved transversal and shear characteristics with excellent properties in the direction of reinforcement.

KEY WORDS Composite, spiral anysotropic media, spiral reinforced filler, adhesion properties

INTRODUCTION

At present fiber composite materials are widely used owing to a wide range of their properties such as high specific strength and rigidity, non-magnetism and transparency to radio waves, all these being regulated within a certain range by heat and electrical conduction values. However, the composites having excellent characteristics in the direction of reinforcement are rather vulnerable in the transversal direction at longitudinal stress and shear. This can be regarded as the main obstacle for their proper application on constructions. This can be explained by the fact that the characteristics of unidirectional materials under such loads are determined by the properties of the matrix and the components boundary which are in a certain degree lower in comparison to the filler characteristics. To improve the physical and mechanical properties of the composite materials there have been created new types of reinforcing fibers and binders. The technological processes have been developed to use the properties of the starting components to the utmost degree, to improve and develop new material patterns and, accordingly, new products. One of the most promising trends is to ensure high quality of adhesion on the components boundary which is of primary importance for the material strength.

The structure and properties of the composite materials are embedded in the production process and, consequently, are determined by certain technological parameters such as impregnation and stress conditions, heat treatment etc. The improvement of the boundary adhesion at the expense of the enlarged contact area permits to improve transversal and shear characteristics and create more favorable operational conditions at different types of loading.

It is possible to improve components boundary adhesion, to eliminate defects in the material pattern and enhance the binder properties using such special technological processes as finishing and magnetic treatment. However, while realizing the components starting properties they do not radically improve the material properties on the whole. The most promising way to improve some properties in a certain range is hybridization and spatial reinforcement of the material.

Some investigations have shown that the most advantageous way to do that is designing interlayer hybrid composite materials with a regular arrangement of high modular fiber bundles. However, manufacturing and application of such materials necessitates solving some important problems. They are the following:

—ensuring regular arrangement of the high modular filler bundles in regard to the low modular fillers;
—reduction of anisotropy of strength and elastic properties of the material;
—investigation of the boundary surface of the hybrid composite;
—the methods of surface treatment of the matching components in order to improve the boundary adhesion.

Combining spatial reinforcement with hybridization seems to solve some of these problems. In this aspect combination of hybridization and spatial reinforcement at the filler level is most promising and permits to produce spiral reinforced fillers as the first stage in the production of composite materials.

RESULTS AND DISCUSSION

The structure of the hybrid spiral reinforced material is the following. It is a system of filler bundles arranged longitudinally. The fibers and threads of these bundles are spirally wound with another fiber material (Figure 1). Henceforth we shall call them spiral reinforced elements. Since the inner fiber bundles (the nucleus of the element) carry the main load applied to the longitudinally arranged reinforcing fibers, they are considered to be the primary reinforcement and the winding fibers

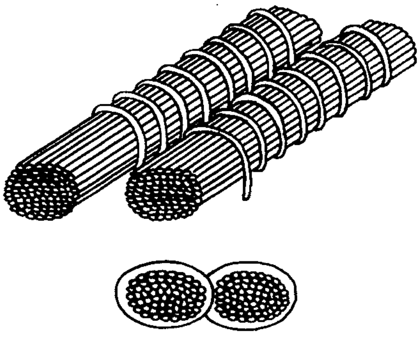

FIGURE 1 Spiral reinforced fillers.

are auxiliary. The auxiliary fibers separating the primary reinforcing bundles are called interlayers.

It is noteworthy that even in the unidirectional composites the spiral auxiliary layer causes the spatial reinforcement of the spiral reinforced element as well as the material in general. The structure of the material and its parameters are mainly determined by the type of the primary reinforcement fibers and auxiliary fibers.

The structure of the given composites may be represented as elliptical elements sited at the points of a double periodic lattice. The parameters of the lattice are ω_1; ω_z; α and cross section values of the spiral reinforced elements are determined by the degree of filling of the primary reinforcement fibers $-\varphi_a$ as well as by spacing of the material layers and by gaps between the elements in each layer. They can be determined using the following equations:

$$\begin{aligned} \omega_z &= R\sqrt{4\gamma^2 + (1 - \gamma^2)(1 + r)^2}\,; \\ \omega_1 &= 2R(1 + r); \qquad tg\alpha = \gamma\sqrt{(1 + r)(3 + r)}\,. \end{aligned} \tag{1}$$

The cross-sectional shape of the spiral reinforced element approximates the ellipse the half-axles of which can be expressed as:

$$\begin{aligned} a &= 0.5[\omega_1 + pctg\alpha(\sqrt{1 + tg^2\alpha} - 1)]\,; \\ b &= 0.5[\omega_2 + p(\sqrt{1 + tg^2\alpha} - tg\alpha)]\,. \end{aligned} \tag{2}$$

At good mechanical compliance of the element, i.e. the low degree of filling with the primary reinforcement and when the reduction reaches a certain limiting value $\gamma = \gamma_0$ there occurs jointing of the auxiliary reinforcement along the element perimeter accompanied with the interpenetration of layers. In this case the spiral reinforced element takes a polygonal shape the dimensions of which depend on the spacing between the layers and the gaps in each layer.

To evaluate the properties of the hybrid spiral reinforced composites one should consider the problems of the composite elastic strain under the stress perpendicular to the direction of the primary reinforcement. Moreover, the interlayers formed on the primary reinforcement surface can have a wide range of geometric, elastic and strength properties: thin and thick, isotropic and orthotropic, circular and non circular.

On the basis of microstructure studies of composites with the spiral reinforced filler there has been selected a representative structure element consisting of a transtropic cylinder with an arbitrary cross section (a circle, an oval, a square, a rectangle with rounded off angles, etc.), a cylindrical orthotropic interlayer of constant thickness and an isotropic matrix (Figure 2).

In this case Kolosov-Mushelishvili complex potentials are used to record the tensor component of stresses and the displacement vector. The complex potentials permit to take into account the heterogeneous properties of the spiral layer throughout its width.

As has been shown by the numerical investigation, introduction of the reinforced filler results in redistribution of stresses in the material structure and in change of in elastic properties. As could be seen from Figure 3 the introduction of the interlayer into the structure has a pronounced effect on the stress values. Thus radial stresses in the matrix reduce by 65%. A change in the degree of filling also leads to the stresses redistribution. In Figure 4 the data on stress changes in the materials with varying degree of filling are given (solid lines $\varphi_a = 0{,}58$, section lining $\varphi_a = 0{,}73$). Judging by the figure it is the normal stresses in the matrix that are mostly

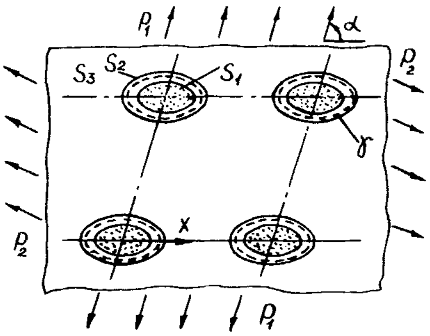

FIGURE 2 The models of the material with the spiral reinforced filler.

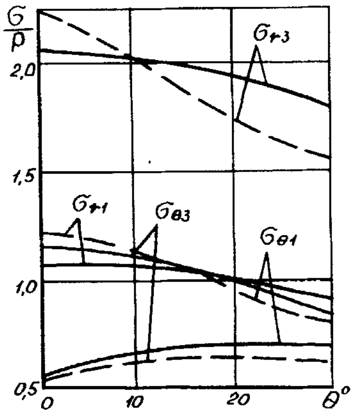

FIGURE 3 Dependence of stresses in the material structure on the angle.

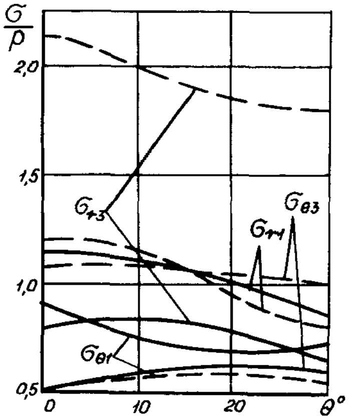

FIGURE 4 Change of normal and tangential stresses for different degrees of filling of the material.

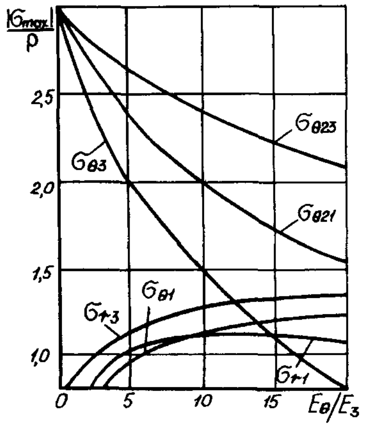

FIGURE 5 Maximal stresses dependence on the interlayer properties.

subjected to the degree of filling. And from Figure 5 it is clear that improving auxiliary layer properties results in reduction of maximal stresses in the matrix as well as in its boundary with the layer, and at the sometimes increases the stresses in the nucleus of the element.

Investigation of the properties of the material components at transversal tension and longitudinal shear is of great importance for estimating the components adhesion. It is expected that at the given loads the properties of the materials with hybrid spiral reinforced filler should improve properties. This can be explained by the interaction between the primary reinforcement fibers and auxiliary fibers, by the adhesion conditions and by enlarging the fibers contact area in the interlayers. Here, in contrast to the usual composites the form of the structure element is very important. Thus speaking about the materials with the spiral reinforced filler one should consider in general the adhesion medium under complex loading. It is noteworthy that the material properties on the whole are determined by the structure element configuration and its formation conditions rather than by the interaction of reinforcing fibers.

In Figure 6 there is shown the transversal elastic modulus dependence on the degree of filling for three types of composites: carbon/organoplastic (curve 1), carbon/glassplastic (curve 2), glassplastic (curve 3) for the $\delta/R = 0.05$ and 0.1. The given data suggest that applying of the interlayer of the higher modulus material results in increasing of the transversal elasticity modulus. Naturally, as the thickness of the interlayer diminishes the elasticity modulus reduces.

The data obtained strongly suggest that applying of the spiral reinforced filler also results in properties change of the composites at longitudinal tension and shear. Thus Figure 7 shows how the thickness of the auxiliary reinforcement layer affects the longitudinal shear modules. As the layer thickness grows the modulus G_{xy} increases. In comparison with the unidirectional materials the longitudinal elasticity modulus increases by 40. . .60%. For the materials with the spiral reinforced filler, as has already been mentioned, the configuration of the element is of great importance. In this aspect they differ from the unidirectional composites in which only circular fibers are used. Also, it has been stated that if the longitudinal shear

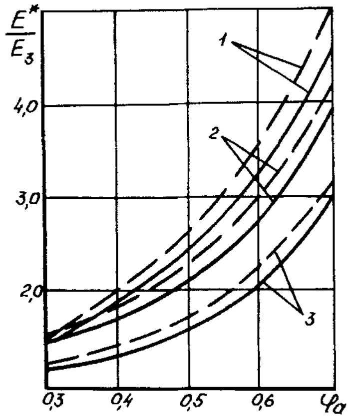

FIGURE 6 Elastic modulus change at transversal tension caused by the degree of filling.

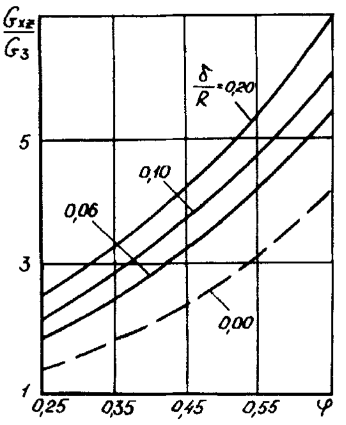

FIGURE 7 Dependence of the longitudinal shear modulus on the degree of filling with the primary reinforcement and the interlayer thickness for the glass-organoplastic.

modules in the plane *ZOX* and *ZOY* are different and determined with the specific dimensions ratio, the longitudinal elasticity modulus does not depend on this parameter.

Thus the given investigation suggests that there is a certain dependence of the studied properties on the properties and geometric dimensions of interlayers.

CONCLUSIONS

This fact leads to the following conclusion. The change in the character of the adhesion interaction in the structure of the given materials permits to design a wide range of new materials with the necessary transversal and shear properties while preserving excellent characteristics in the direction of reinforcement. The experiments confirm the theoretical investigation and indicate that the designed material structure with the hybrid spiral reinforced filler gives composites with the improved characteristics under transversal load, shear and longitudinal stress.

NOMENCLATURE

G_{xz} = longitudinal shear modulus;
h = gap between the elements and the layer;
p = coefficient taking rout account the starting degree of the element filling;
R = radius of the starting spiral reinforced filler;
γ = limiting value of γ_0;
$\gamma < 1.0$ = degree of the material reduction;
δ = thickness of the interlayer;
θ = the angle;
φ_a = degree of filling of the primary reinforcement fibers;
ω_1, ω_2, α = the parameters of the lattice.

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