Polskie Towarzystwo
Materiałów Kompozytowych
Polish Society of
Composite Materials

Kompozyty 11: 1 (2011) 80-83

KOMPOZYTY
COMPOSITES

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Otrzymano (Received) 10.02.2011

INFLUENCE OF REINFORCEMENT PHASE FORM ON BENDING STRENGTH OF POLYMER COMPOSITES

Composites belong those materials that are systematically developed due to the rapid technological advancements observed in recent years. These materials are successfully used in various fields just because it is possible to obtain the desired properties through adequate selection of the reinforcement and matrix, the components of a new material. It is important, however, that the distribution of the reinforcement phase be as uniform as possible, particularly in laminates, where reinforcement layers undergo saturation. If this requirement is satisfied, the composite has good quality, especially when high material strength is the desired property. In this study, two kinds of laminate composites that differ in their reinforcement type are compared. In both cases, the reinforcement was composed of glass fiber (a mat, made of roving, cut into short pieces, chaotically placed in a plane; and a woven fabric, made of long roving, produced by interweaving bundles of fiber glass at a right angle in the plane). The matrix was epoxy resin (Epidian 5 with Z1 hardener). A series of samples was prepared, that differed in the number of reinforcement layers (3, 6, 9, 12). They were tested for bending according to the PN-EN ISO 178 standard: 'Synthetic materials: determination of properties in bending tests', using a testing machine H10K-T. The test results lead to a conclusion that the best bending properties are obtained for laminates with reinforcement arranged in the form of a fabric, which is due to the advantageous distribution of stresses on the long fibres of the reinforcement. Bending strength also depends on the number of reinforcement layers. In this respect, both types of material (mat, fabric) with nine layers yield the best results. The calculated values will be utilized in further research for the creation of a mathematical model describing the strength of tested laminates depending on the number of layers and type of reinforcement phase.

Keywords: polymer composites, flexular strength

WPŁYW POSTACI FAZY ZBROJĄCEJ NA WYTRZYMAŁOŚĆ NA ZGINANIE KOMPOZYTÓW POLIMEROWYCH

Materiały kompozytowe należą do grupy materiałów, których technologia rozwija się w ostatnich latach bardzo szybko. Materiały te swój sukces zawdzięczają możliwości uzyskania korzystnych właściwości przez umiejętne dobranie wzmocnienia i osnowy stanowiące komponenty nowego, innego materiału. Ważne jest jednak, aby rozkład fazy wzmocnienia (szczególnie w przypadku kompozytów warstwowych wytwarzanych przez nasycanie) był możliwie równomierny. Zapewnia to dobrą jakość kompozytu i jest bardzo ważnym elementem z punktu widzenia wytrzymałości materiału. W pracy porównano dwa rodzaje kompozytów w formie laminatów różniące się typem fazy wzmocnienia. Wzmocnienie stanowiło w obu przypadkach włókno szklane (w pierwszym przypadku: maty wykonanej z rovingu ciętego na krótkie odcinki, które były rozłożone w sposób chaotyczny w płaszczyźnie; w drugim: tkaniny wykonanej z rovingu długiego, powstającego w wyniku przeplatania ze sobą wzajemnie prostopadłego ułożenia pasm włókna), osnowę: żywica epoksydowa (Epidian 5 z utwardzaczem Z1). Przygotowano serię próbek w układzie 3, 6, 9, 12 warstw wzmocnienia, które poddano próbie zginania zgodnie z PN-EN ISO 178 („Tworzywa sztuczne: oznaczanie właściwości przy zginaniu"), na maszynie wytrzymałościowej H10K-T. Jak wynika z przeprowadzonych badań, najlepsze właściwości na zginanie daje zastosowanie w laminacie wzmocnienia w formie tkaniny, co spowodowane jest korzystnym rozkładem naprężeń w długich włóknach wzmocnienia. Wpływ na wytrzymałość na zginanie ma również ilość warstw wzmocnienia i w obu badanych przypadkach (tkanina, mata) najkorzystniej wypada laminat o 9 warstwach wzmocnienia. Wyznaczone wartości będą podstawą (w dalszych badaniach) do stworzenia modelu matematycznego opisującego wytrzymałości badanych laminatów w zależności od ilości warstw i rodzaju fazy wzmocnienia.

Słowa kluczowe: kompozyty polimerowe, wytrzymałość na zginanie

INTRODUCTION

A simple and unequivocal explanation of the term *composite* is not possible as there is no universal definition that would encompass all kinds of composite materials.

The most common definition, the one formulated in 1967 by Broutman and Krock [1-5] reads:

1. a composite is an artificially produced material
2. a composite consists of at least two chemically different materials, with clearly separate components (phases)
3. the components have characteristic volumes in the composite

4. a composite is characterized by properties that each of the components separately does not have

This definition is variously presented in literature and does not comprise all groups of materials. It does not include natural composites, plated or laminar materials [4, 5]. Another definition of composite material that is not very precise and rather broad was formulated by Javitz in 1965, who is of the opinion that a composite material is one that is not a pure substance [5-8]. Definitions are often modified and sometimes ambiguous, therefore it is herein worthy of taking a look at the definition provided by the PWN published *Encyklopedia Powszechna* in its 1988 edition. According to this source, a composite is *"a material consisting of at least two components (phases) with different properties, made in a manner that makes its properties better and (or) creates new (additional) properties as compared to the separate components, or resulting from simple adding of these properties; the external surface of a composite is monolithic, although it has visible boundaries between the components"* [3, 5, 6, 9].

Composite material has to be made of at least two phases, one of which is called the reinforcement, the other the matrix. One characteristic quality of composite materials is that both the reinforcement and the matrix fulfil certain functions and both components are complementary. The reinforcement phase generally improves (compared to separate components) the strength properties of the ready product, often increases its abrasive wear resistance; it may reduce thermal expansion in the product, and raises its resistance to thermal shock; the reinforcement also stops the spreading of cracks in the composite [1-6, 10]. Characteristic features of composite materials are often non-homogeneous distribution and the content of the reinforcement phase in the volume of the material, as well as the varying form, shape and size of this structure component [11]. It follows from the fundamentals of materials engineering that this type of differentiation of the structure substantially affects its widely understood properties.

The matrix [5, 6], on the other hand, maintains the system in a compact form; it transfers external loads onto the reinforcement; it protects the reinforcement against mechanical damage and renders the specific shape of the products. The matrix is more or less homogeneous material filling up the space between the reinforcement elements. The volumetric content of the matrix may range from 10 to 80% of the composite volume. Composites are often classified by the matrix material [4, 7]:

1. polymer composites,
2. metallic composites,
3. ceramic composites.

At present, in engineering applications, polymer composites take the lead, particularly those belonging to the group of duroplasts, i.e. unsaturated polyester resins (due to their price), vinyl resins (higher chemical hardening capacity than other resins) and epoxy resins (due to good mechanical properties used in aircraft structures).

This work aims at testing two types of laminate composites that have a different reinforcement phase. In both cases, the reinforcement consisted of glass fiber (mat in one material, woven cloth in the other), while the matrix in both cases was epoxy resin (Epidian 5 with Z1 hardener). A series of samples was prepared for bending tests performed in compliance with the PN-EN ISO 178 standard [12].

EXPERIMENTAL PART

The tests were carried out to compare two types of composite (with the same matrix and the same reinforcement material). The aim was to check the bending, or flexural, strength depending on the reinforcement phase type, which in the tested material had the form of:

- **mat**, made of roving cut into pieces which are 25÷÷30 mm long, chaotically placed in a plane. The mat coherence is ensured by an adhesive, used to glue pieces of roving;
- **woven fabric**, made of continuous interwoven rovings, like in linen, bundles of fiber glass were interwoven at a right angle in the plane.

The laminate samples were made according to the standard 'Synthetic materials: determination of properties in bending tests' [12]. Laminates, with 3, 6, 9, 12 layers of reinforcement, were prepared by saturating the material segments, using a brush, with epoxy resin *Epidian 5* and the Z1 hardener, at a 1:10 ratio. Thus the prepared laminates were tested for three-point bending, according to the PN-EN ISO 178 standard (Fig. 1), using the testing machine **H10K-T** (the tests were repeated three times on identical sets of samples, in order to verify the results - average values were calculated).

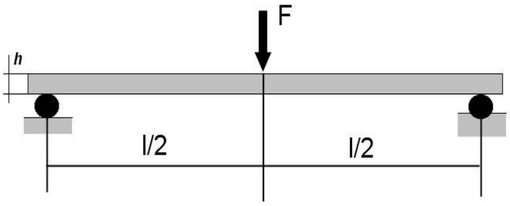

Fig 1. Diagram of three-point method of sample load during bending tests

Rys 1. Schemat sposobu obciążenia próbki w próbie zginania tzw., „trzypunktowy"

RESULTS AND DISCUSSION

The said standard provides for the use of cubicoid samples, where the length-height ratio is l/h = 16. The averaged values of height (*h*) equivalent to the number of layers of reinforcement material in laminates are shown in Table 1. This requirement ensures that destruction caused by normal stresses connected with the bending moment will occur before the splitting of the layers due to tangential stress [8-12].

TABLE 1. **Averaged sample heights (*h*) corresponding to number of layers in laminate (mat, fabric)**

TABELA 1. **Uśredniona grubość próbek (*h*) odpowiadająca ilości warstw w laminacie (mata, tkanina)**

MATERIAL	MAT			
Number of material layers in laminate, pieces	3	6	9	12
Average sample height h mm	2.9	5.2	8.6	10.7
MATERIAL	FABRIC			
Number of material layers in laminate, pieces	3	6	9	12
Average sample height h mm	1.7	2.2	3.3	4.0

Figure 2 presents the values of the applied force F depending on the number of layers in the tested laminates.

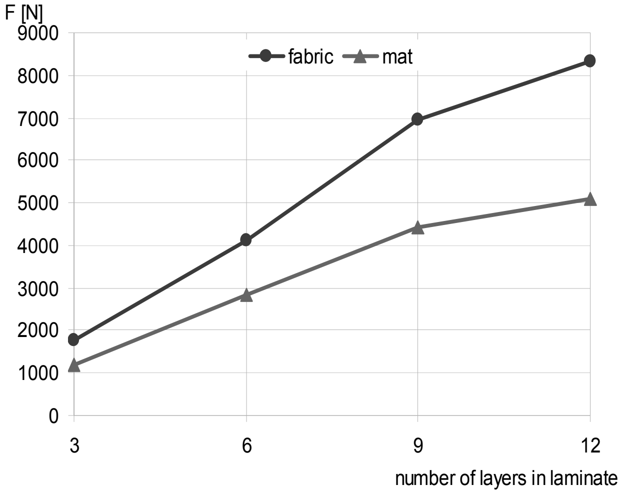

Fig. 2. Values of applied force *F* depending on number of layers in tested laminates

Rys. 2. Wartość przyłożonej siły *F* w zależności od ilości warstw dla badanych laminatów

The bending theory developed for homogeneous and isotropic materials is used for the assessment of non-homogeneous and strongly anisotropic materials, and is also commonly adopted for the tests of composites examined in the direction of fibre position [11-13]. Based on the above experimental data, the bending strength of the tested composite materials was determined as the greatest value of stress σ_f according to this formula [12, 14]:

$$\sigma_f = \frac{3Fl}{2bh^2} \quad (1)$$

where: σ_f - bending stress, MPa, F - applied force, N, L - length between supporting points, mm, b - sample breadth, mm, h - sample height, mm.

Table 2 includes the bending stress figures depending on the number of layers in the tested laminates.

TABLE 2. **Values of bending stress depending on number of layers in tested laminates**

TABELA 2. **Wartości naprężenia zginającego w zależności od ilości warstw w badanych laminatach**

MATERIAL	MAT			
Number of material layers in laminate, pieces	3	6	9	12
σ_f, MPa	97.4	131.3	123.2	114.4
MATERIAL	FABRIC			
Number of material layers in laminate, pieces	3	6	9	12
σ_f, MPa	249.2	449.3	506.4	500.1

CONCLUSION

Many common laminate composites consist of layers in the form of mats or woven fabric. The high strength of the fibres in these materials makes them suitable for a wide range of applications, e.g. pressure pipes, high pressure tanks and the aircraft industry [8, 15, 16]. Owing to the wide choice of matrix materials and different forms of the reinforcement phase, new properties of composites are still being discovered, and consequently, new structural or functional materials are developed.

The test results have shown that composites with woven fabric reinforcement have the greatest bending strength (Tab. 2). This can be explained by the favourable distribution of of load in the material, which is guaranteed by the long continuous fibre of the fabric. It has been also found that the number of layers in the laminate affects the strength (see the applied force F in Fig. 2 and Tab. 2). The highest value of bending stress was reached for the sample with the 9-layer laminate (for both types of composite reinforcement). The empirical values make up a basis for the creation of a mathematical model describing the strength of tested laminates that is dependent on the number of layers and the type of reinforcement phase.

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