

Experimental Evaluation of The Durability of A Composite-Composite Pasted Assembly Under Quasistatic Loading

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ABSTRACT

Optimization of composite structures for the design and repair through, in particular, the use of pasted junctions in lieu of bolted or riveted junctions for different applications. The object of this work is to model the durability of a pasted assembly of composite structures under quasistatic loads by the hereditary Rabotnov approach. To do this, it took on the one hand, an experimental analysis of the damage of the adhesive in shear behavior subjected to different loading rates. On the other hand, the establishment of the model required experimental identification of the parameters of the creep kernels in formulating expressions for determining the durability and long-term strength limit in the shear of glued composite assembly. Special attention is paid to the prediction of the strength characteristics of the material under long loading periods up to 10^6 h (approximately 100 years of operation) by laboratory tests carried out for 10^3 h.

The results could be useful, in particular, when designing and assembling the elements in composite structures located in bridge decks and walkways (beams, spacers, etc.) and also in shipbuilding.

Key words: Composite-composite pasted assembly, durability, prediction, quasistatic loading

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I. INTRODUCTION

Structural bonding is a promising technique to increase the performance of composite structures. The assembly of composite materials by collage has undisputed advantages compared to other methods such as bolting or riveting. However, the main difficulty is to provide the level and mode of failure of these assemblies. Optimization of composite structures for the design and repair through, in particular, the use of junctions pasted in lieu of junctions bolted or riveted for different applications [1,2]. In the field of civil engineering, the technique of repairing and strengthening of concrete structures by bonded composites, for example, is now commonly practiced, thus allowing an increase in the durability of the parks of works out of concrete [3]. In particular, the composite materials are used for the assembly of elements of structures located in the bridge decks (beams, spacers, etc). However, these structures are conceived for long durations of exploitation and must resist more or less severe mechanical constraints. For the realization of such structures, one can use, for example, the laminated glass-polyester composites. These parts are subjected to quasistatic and dynamic stresses. Therefore, it is important to be able to correctly provide answer solicitations in nature as different models of behavior. Studies within this framework have been developed in [4-6]. With regard to the glued composite joints, the strength and durability of the joints are a complex function resulting from the balance between the constraints of adhesion or cohesion of materials and concentrations of constraints caused by the load, in which shear constraints play a crucial role. On the other hand, at the time under load, the stress distribution is uniform in the region stuck, avoiding local concentrations of constraints that exist, for example, in the areas of joints of structures and mechanical assemblies.

Thus, the bonded structures have a durability longer than those assembled mechanically.

Nowadays, most of the forecasting models of viscoelastic behavior of the materials are based on analogies or Ferry's time-temperature equivalence principles, in which the temporal variable is a function of the temperature. This approach is suitable for the analysis of the thermorheological process. It is especially convenient for engineering calculations because one can instantly test under high temperature and predict the behavior of the material for low temperatures for extended loading periods. However, this approach is possible only in a domain of stationary creep in which deformations increase linearly with time. On the other hand, when the material is subjected to high temperatures for long periods, a change in the structure of the material is caused, thus posing a problem of reliability of this model. In addition, it is impossible to use a time-temperature equivalence model to describe the transition to the nonstationary field of creep curves. Accordingly, another predictive approach to creep, taking into account these shortcomings, is the use of a model with a representation to hereditary character of deformation of materials with the use of Volterra integral equation with different creep kernels. This approach does not require the introduction of a thermal variable but the main question is the choice of the kernel of the integral equation, which has a great influence on the results of the forecasting model.

This work proposes a predictive method of damage to model the durability of glued composite assembly subjected to quasistatic loads. Special attention is paid to the prediction of the strength characteristics of the material under long loading periods up to 10^6 h (approximately 100 years of operation) by laboratory tests carried out for 10^3 h.

2. MATERIALS AND METHODS

The substrate used is a glass-polyester orthotropic composite thermosetting matrix having been the subject of a characterization [Table 1] [7]. The object of study used for bonding adhesive is an epoxy bicomponent, thermosetting resin RDK-2 [Figure 1], because only thermosetting resins can withstand updates under significant loads and are, therefore, suitable for use as structural adhesives only. On the other hand, this glue was chosen for:

- Its refractive index (n) = 1.529.
- Its glass transition temperature of 30° which is a temperature low enough to allow dissipation of energy in the glue joint and absorb a thermal shock without as much a creep of glue under mechanical stress.
- The ability to apply it in thicknesses in the range 10-15 μm .

For this study, we will use the principle of hereditary character of deformation and damage accumulation process developed by Rabotnov [8]. In this context, we consider the following expression:

$$\varphi(\varepsilon) = \sigma + \int_0^t V(t-\xi)\sigma(\xi)d\xi + \int_0^t D(t-\xi)\sigma(\xi)d\xi \quad (1)$$

$\varphi(\varepsilon)$ -instantaneous deformation curve corresponding to the time (t) = 0.

$V(t-\xi)$ and $D(t-\xi)$ - the kernels of the integral equation. The first kernel characterized reversible viscous deformation and the second characterized an irreversible process of accumulation of damage.

In the case of the nonviscous material expression Equation (1) will include only the kernel characterizing a process of progressive failure of it:

$$\varphi(\varepsilon) = \sigma + \int_0^t D(t-\xi)\sigma(\xi)d\xi \quad (2)$$

From Equation (2) we have the strength criterion:

$$\sigma_{[0]^*} = \sigma + \int_0^t D(t-\xi)\sigma(\xi)d\xi \quad (3)$$

$\sigma_{[0]^*}$ -is endpoint of the instantaneous deformation curve (resistance of the material free from any defect).

From Equation (3) we can give the following conclusions:

- The existence of a link between the loading speed and the strength of the material, greater the loading speed, higher the value of the resistance, which is explained by the lessening of damage in the structure of the material.
- The existence of a link between the speed of loading and deformation, lower the speed, greater will be the strain at break of the material.

The stuck assembly studied in this work has no signs of creep after hardening during the experimental tests. This allows the application of the Equations (2) and (3).

Based on the foregoing, in the case of shear, Equation (3) can be written in the following form:

$$\tau_0 = \tau + \int_0^t D(t-\xi)\tau(\xi)d\xi \quad (4)$$

In this Equation, τ characterizes the shear stresses, τ_0 characterizes a constant specific to the material, corresponding to the limit of the shear strength of the material free from any internal defect likely to spread in time (or corresponding to a load on a time t_0), $D(t-\xi)$ characterizes kernel of the integral relationship in Equation (3) to be identified experimentally.

Table 1: Elastic characteristics of composite KACT-B

Characteristics of the composite KACT-B	Static loading	Long-term loading
E_x , MPa	$2.22 \cdot 10^4$	$1.95 \cdot 10^4$
E_y , MPa	$1.75 \cdot 10^4$	$1.53 \cdot 10^4$
E_z , MPa	$0.4 \cdot 10^4$	$0.32 \cdot 10^4$
G_{xy} , MPa	$4 \cdot 10^3$	$4 \cdot 10^3$
G_{yz} , MPa	$2 \cdot 10^3$	$2 \cdot 10^3$
G_{zx} , MPa	$1 \cdot 10^3$	$1 \cdot 10^3$
μ_{xy}	0.13	0.23
μ_{yz}	0.45	0.6
μ_{zx}	0.1	0.12

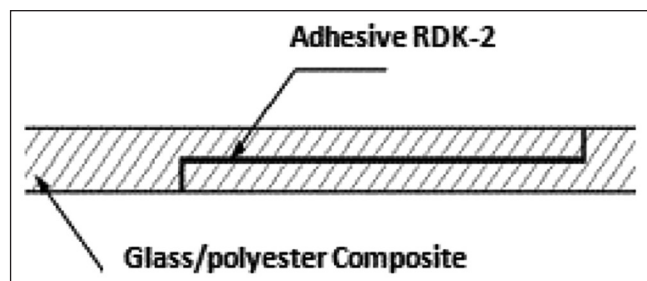


Figure 1: Composite-composite pasted assembly by adhesive RDK-2

3. RESULTS AND DISCUSSION

In case of an Abelian kernel of type $D(t-\xi) = \frac{a(1-\beta)}{(t-\xi)^\beta}$ ($0 < \beta < 1; 0 < a$), the integration of the Equation (4) relationship for $\tau = \text{constant}$, which will give:

$$\tau_0 = \tau(1 + at^{1-\beta}) \quad (5)$$

At limit state, becomes the long-term shear strength limit of the material:

$$\tau_* = \frac{\tau_0}{1 + at_*^{1-\beta}} \quad (6)$$

In the Equation (6) t_* represents the life time of the material:

$$t_* = \left[\frac{1}{a} \left(\frac{\tau_0}{\tau_*} - 1 \right) \right]^{\frac{1}{1-\beta}} \quad (7)$$

We know that the Equation (5) is a power relationship that aptly describes the processes of deformation and fracture in the case of small load times. You can also see that when $t \rightarrow \infty$, $\tau \rightarrow 0$. However, a number creep and long-term strength tests on these materials [9-11] showed an exponential relationship between the stress and the speed of loading in the case of long

load times. This means that the kernel of the model must be of exponential type.

In this case, we will consider the following Slonimsky's kernel:

$$D(t) = \frac{y\alpha\beta e^{-y\cdot t^{1-\beta}}}{t^\beta}, (0 < \beta < 1; 0 < y; 0 < a)$$

By postponing this kernel in the Equation (4), we obtain after integration the following Equation:

$$\tau_0 = \tau \cdot [1 + a(1 - e^{-y\cdot t^{1-\beta}})] \tag{8}$$

Using the kernel of Slonimsky, at limit state, will be the long-term shear strength limit of this material:

$$\tau_\infty = \frac{\tau_0}{1 + a(1 - e^{-y\cdot t_\infty^{1-\beta}})} \tag{9}$$

where life time t_∞ in this case will be:

$$t_\infty = \left\{ -\frac{1}{y} \ln \left[1 - \frac{1}{a} \left(\frac{\tau_0}{\tau_\infty} - 1 \right) \right] \right\}^{\frac{1}{1-\beta}} \tag{10}$$

In Equation (8) we see that when $t \rightarrow \infty$ τ tends to value nonzero $\frac{\tau_0}{1-\lambda}$, so in this case there is a lower asymptote, limiting constraints decay over time.

3.1 Quasistatic tests

Shear tests carried out in the context of this work are described by the standards [12,13]. Their aim is to determine the influence of the speed of solicitation on the characteristics of the shear strength of glued assembly object of this study and on the other hand, the determination of the parameters of kernels using the Equations (5) and (6). These tests are carried

out for different loading rates: 0.75 MPa/min, 2.07 MPa/min, 20.7 MPa/min, and 206.7 MPa/min. The values of the shear for different loading rates are presented in Table 2 and Figure 2.

We can see in Figure 2 that the characteristic of resistance to shear of glued assembly increases with the loading speed. On this basis we can say that the character of rupture corresponds to the principle of accumulation of damage. Less loading speed is great (so long is the loading time), lower is the resistance due to the high values of the accumulation of damage.

3.2 Long-term strength tests

These tests are described by the standards [14,15]. For the glued assembly, the tests determine the average value of the breaking load which is $P = 21$ MPa. From this value, the values of loads for long-term strength testing are determined. These values are 0.9 P , 0.8 P , 0.7 P , and 0.6 P . The long-term strength tests on this glue are intended to conduct a predictive assessment of 10^6 h (approximately 100 years of operation) from tests to a loading duration equal to 10^3 h (approximately 6 weeks).

3.3 Determination of the parameters β , α , and γ

The determination of the parameters of the model is done using two kernels (the Abelian kernel and the Slonimsky kernel) and long-term strength curves. Figure 3 presents long-term strength curves, one at the Abelian kernel and the other at the exponential Slonimsky kernel.

Parameters α and β are determined using the curve to the Abelian kernel in time intervals of loading between 0 h and 10^{-9} h, as Abelian kernels are renowned for their efficiency in small load times.

The parameter γ is determined using the exponential Slonimsky kernel curve. Load times are $t = 1$ h ($\log t = 0$) and $t = 1000$ h ($\log t = 3$), respectively.

Finally for this material, $\tau_0 = 25$ MPa is the limit of the shear strength and is determined for a period of $t = 1$ h loading.

The values of the parameters are presented in Table 3.

Table 2: Values of the shear stresses

Material	Loading speed, MPa/min	Average value of the shear strength, $\bar{\tau}$ MPa
Two-component epoxy RDK-2	0.75	15.1
	2.07	15.4
	20.07	15.9
	206.7	19.5

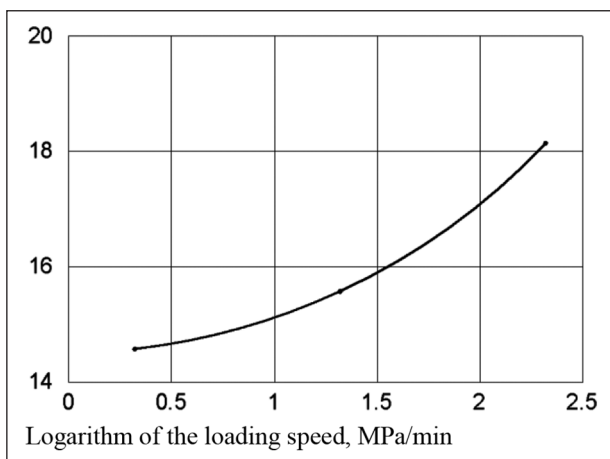


Figure 2: Loading speed-stress of shear curve in the bonded assembly

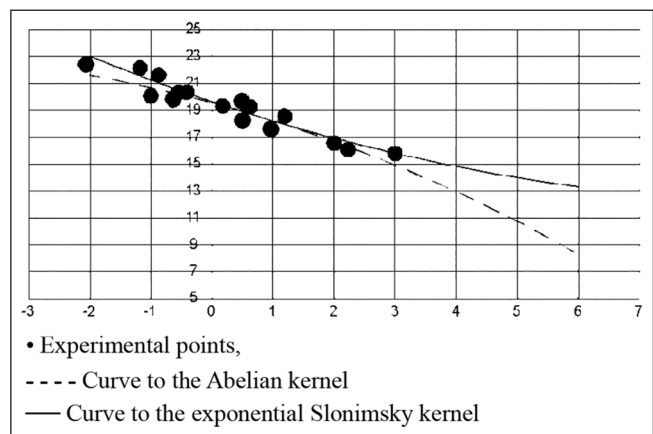


Figure 3: Long-term strength curves at the Abelian and Slonimsky kernels

Table 3: Values of the parameters

Parameters	Abelian kernel	Slonimsky kernel
τ_0	25	25
β	0.848	0.848
α	0.036	0.79
γ	—	0.4034

4. CONCLUSIONS

In this work, we can infer the following:

1. An experimental analysis of the durability of a two-component epoxy glue for the assembly of elements of structures in composite glass/polyester material thermosetting matrix is made.
2. Using the hereditary approach in long-term breaking problems enables the establishment of a long-term forecasting model based on experimental data obtained in the laboratory.
3. This approach allows the experimental determination of the different parameters of the hereditary model for this material.
4. It has equations to evaluate the durability to shear of a composite-composite pasted assembly stuck and the long-term strength limit in shear of the material.
5. The analysis of the various kernels of damage accumulation models gives the possibility of establishing limits for their use.

This proposed predictive method allows the establishment of the durability of bonded assemblies composite structures subjected to quasistatic loads of long durations, especially when assembling the elements of civil engineering structures such as elements of aprons of bridges and in shipbuilding.

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