

The effects of water aging on the mechanical properties of glass-fiber and kevlar-fiber epoxy composite materials

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1. Introduction

Composite materials with organic matrix are widely used in the international market as materials of choice: they are applied in the fields of the aerospace, naval constructions, etc. This occurs due to their competitive costs and high specific properties (e.g., an excellent withstanding the corrosion). In spite of data shortage in long-term use of these materials, their successful usage can not be proved, and the main reason may be their durability.

In nowadays it is possible to find the reliability and visual representation of composite materials durability using accelerated tests with precise controlled conditions, which can be realized in the environment of laboratory. The durability of composite materials directly depends on the properties of individual structure elements [1, 2].

The humid environment (tap water) is acting in the long run on these materials characterizing their physical-chemical characteristics (temperature, composition, etc.). Its aggressive action appears under several aspects of biological, chemical, physical, and mechanical properties by altering materials in provoking a fail of the mechanical characteristics in time. The interactions of water-polymer (distribution of the water in the composites structures) and mechanical action (damage of the structure) are the most critical factors.

The degradation of the composites is introduced as a phenomenon of plastification or physical aging as the result from the distribution of water in the polymer matrix at the level of the fiber-matrix interface [3, 4]. The phenomenon of hydrolysis or chemical aging takes place in the level of micromolecular chains, eventually generating damage by osmotic fissuring [5].

The aim of this work is to estimate the effects of the tap water on the behaviour of two composite materials composed of epoxy resin with glass fiber and with Kevlar fiber. The effects of these materials behaviour of the fatigue and the aging in the tap water are also analyzed in this study.

Some tests were done to try the characteristics of non subjected to fatigue and immersion the materials for various numbers of cycles in order to determine the evolutions of damage under local interactions of the humidity and fatigue. The analysed material was placed in the humid environment for various durations in order to have a comparison for determination of the aging effect on the fatigue process.

2. Materials and tests

Two types of materials with glass fiber and with Kevlar fiber were produced at the LAUM (Acoustic Laboratory of the University of Maine). The plates of composite

were realized by vacuum molding using various fabrics for the absorption of the resin excess and for their extraction. This operation is done under a 0.3 bar vacuum for 6 hours, with the help of vacuum pump, followed by 8 hours polymerization in 80°C electric heater. Afterwards specimens are cut with the recommended dimensions (200x20x1 mm), using a saw with diamond disk. Fiber's mass rate in materials is determined by calculation and loss during the process of burning. Tests were done by choosing three durations of hydrothermal aging periods: 100, 500 and 1000 hours. This choice of the aging durations is based on the well known experiments in order to define the behaviour of materials in humid conditions. Damage by osmotic cracking related to very important water absorption was identified beyond 120 hours of aging. These results confirm the state of the material damage [6]. The specimens reach quick balance (35 days) within 20°C and a model of Frick makes it possible to describe the kinetics of absorption correctly in 0.35% of absorption [7].

The interactions between humidity and the damage by fatigue could be done only on a local scale, after capillary diffusion of humidity in the bottom of rupture at a temperature of 23°C [8].

The loss of properties is due to reversible phenomena of the matrix plastification until 50°C [9].

The temperature of the medium of aging in this experiment is particular that the tap water is equal to the ambient temperature (15 - 25°C).

The protocol of the tensile tests of studied composite materials is done in 3 stages (Fig. 1):

- the 1st stage of loading is done at a constant speed of 1mm/mn under the displacement controlled up to 50% of displacement to the rupture in statics;
- the 2nd stage is a phase of fatigue with a form of sinusoidal wave of 10 Hz frequency with the amplitude of 10% of displacement to the rupture. The optionally ten numbers of fatigue cycles were chosen and they are in a period from 100 to 50000 cycles;
- the 3rd stage is a phase of unloading of the specimens after being subjected to fatigue with the imposed number of cycles.

At the end of the 3rd stage the specimens can be tested in two different stages:

- either they undergo aging (by immersion) with tap water throughout 100, 500 or 1000 hours (4th stage, Fig. 1), then they are broken by 1mm/min speed of tensile until rupture (5th stage, Fig. 1);
- either they are broken directly by 1mm/min speed of traction without aging (5th stage, Fig. 1).

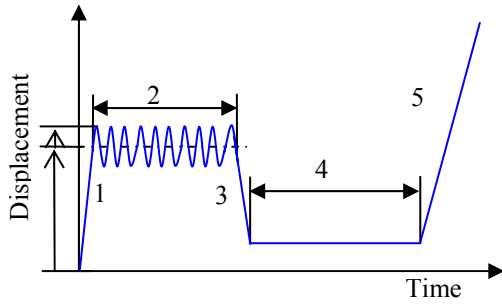


Fig. 1 The protocol of the test-specimen tensile tests

3 Results and discussion

3.1. Static tests

In order to follow the behaviour and the degradation of composite materials studied in wet medium state, static tests in traction were carried out with the goal to determine the forces and displacements with the rupture. At least five specimens were tested in statics state for each material. The obtained results are shown in Fig. 2. This represents the evolution of the stress according to the strain of two studied materials.

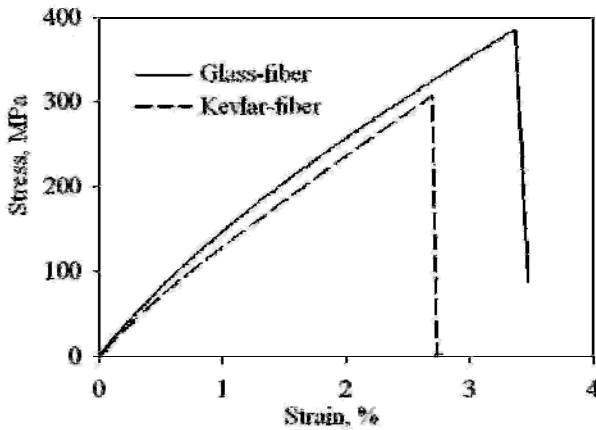


Fig. 2 Static test stress-strain diagram

Table

Static test results		
Mechanical characteristics	Glass fiber	Kevlar fiber
Surface mass, g/m ²	300	170
Fiber, %	65	42
Longitudinal module, GPa	16	16.5
Transversal module, GPa	16	16.5
Stress of the rupture, MPa	380	305
Deformation of the rupture, %	3.5	2.7

A quasilinear behaviour was observed until the rupture of fragile type for both laminates. The value of laminate rupture stress with glass fibers is higher than that of the fiber laminate of Kevlar owing to the fact that the percentage of fibers in the first laminate is higher than that of the second laminate. Table summarizes the results obtained in static tensile on two materials.

3.2. Fatigue tests before aging

These tests are carried out by controlling displacement. Average of displacement was being maintained as a constant. The evolution of the maximum loading force F_{max} according to the number of cycles N was recorded during these tests. The results obtained in the case of a fatigue test of both materials are shown in Fig. 3. It shows the evolution of the F_{max}/F_{0max} ratio according to the number of cycles of fatigue (F_{0max} is the maximum load obtained in the first cycle). The obtained results show that the loss of rigidity (measured by the F_{max}/F_{0max} ratio) until the rupture of the specimen proceeds in three stages: initially it appears by a brutal reduction in the F_{max}/F_{0max} ratio as of the first cycles, the reduction becomes very slow in the second phase corresponding the near total durability of the specimen and finally in the third very short phase where the loss of rigidity accelerates brutally until the fracture of the specimen.

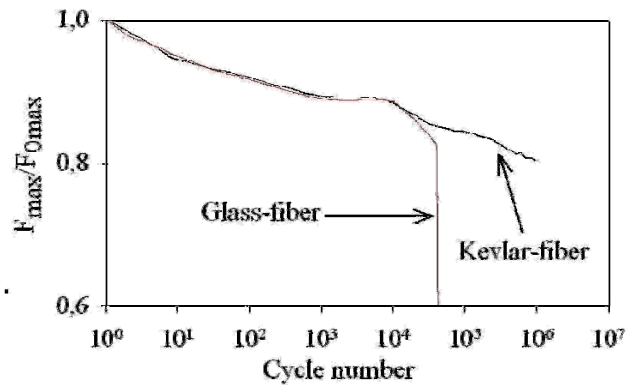


Fig. 3 Results of the fatigue tests

Three specific parts of the curve can be attributed to:

- the initiation and multiplication of transverse ply cracking in the resin for the first part;
- the stable spread of this one as well as the initiation of delaminations between adjacent plies during the second part;
- the accumulation of cracking involving delamination of the layers and rupture of the fibers thus causing the final rupture of the specimen for the last part.

The evolution of the rigidity in 3 stages in literature was explained so: the first stage corresponds transverse ply cracking; the second stage corresponds layers delamination and finally the third stage corresponds fibers breakages [10-12].

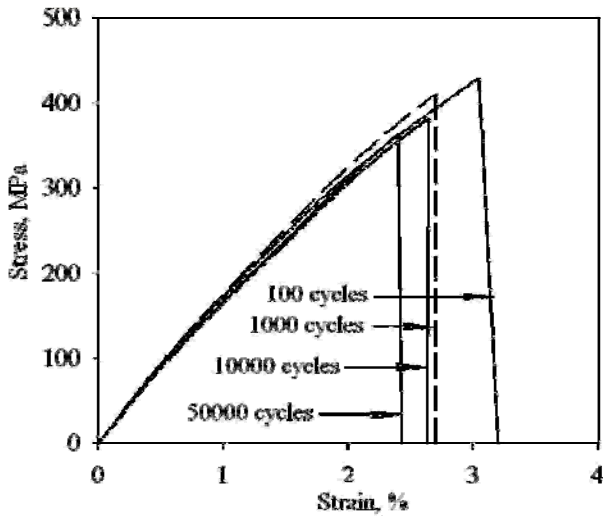
It should be noted that the first stage constitutes only 10% of the life expectancy while it corresponds 80% of the rate of damage.

The specimen of glass fibers brakes before reaching 50000 cycles, whereas rupture of the specimen in Kevlar fibers is not reached at the end of a million cycles.

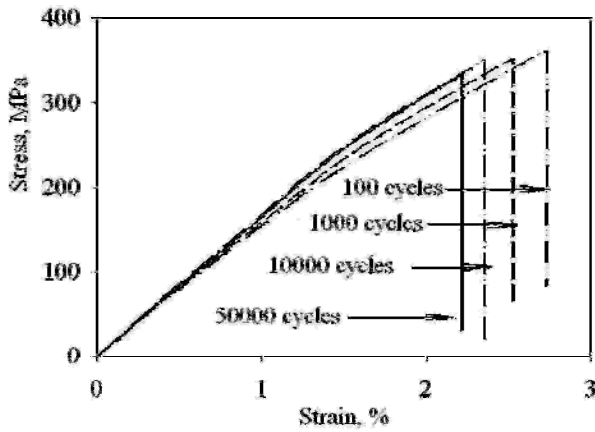
3.3. Static strength and stiffness after fatigue loading

Monotonous static tests were carried out in order to evaluate mechanical behaviour of both materials after fatigue with various numbers of cycles, e.g. Fig. 4 show the stress-strain curves for the Kevlar fibers laminate and glass fibers laminate for four numbers of fatigue cycles (100, 1000, 10000 and 50000 cycles). From these results it is clear the reduction

in the ultimate stress and ultimate strain when the number of cycles fatigue increases for the both laminates.



a



b

Fig. 4 Results of the static tests after fatigue: a) glass fibers laminate, b) Kevlar fibers laminate

Fig. 5 shows the evolution of residual strength obtained in statics according to the number of fatigue cycles for both laminates in a semilogarithmic scale. These results show that the resistance strength of material decreases with the increase in the number of fatigue cycles. In the same way (Fig. 6), the delay of the residual stiffness evolution (slope at the origin of the static test after fatigue) according to the number of fatigue cycles is represented for the both laminates. It could be noted that the module residual stiffness falls with the increase in the number of fatigue cycles for both laminates (with glass fibers and with fibers of Kevlar).

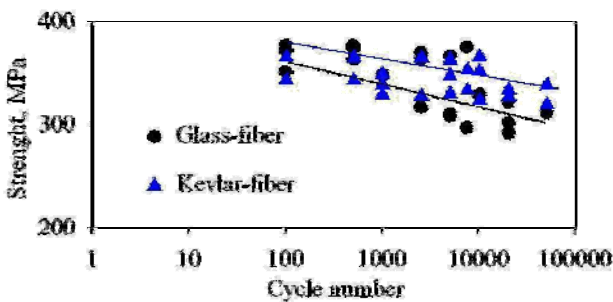


Fig. 5 Residual strength according to the number of cycles fatigue

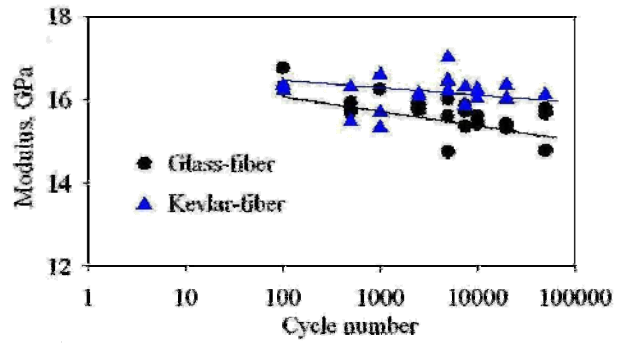
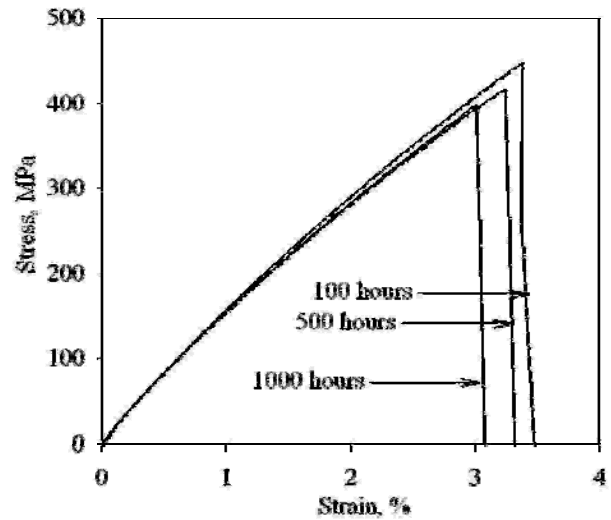


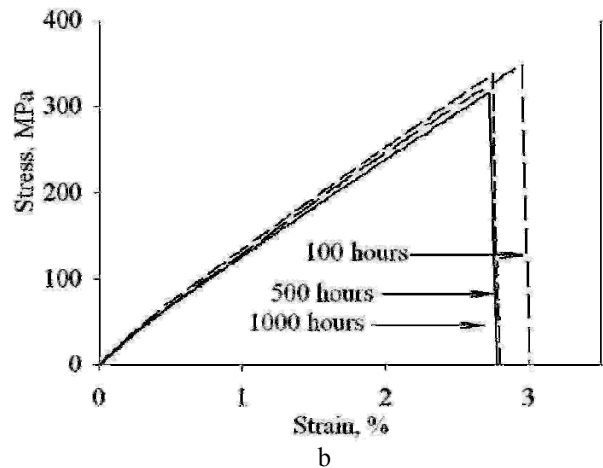
Fig. 6 Residual stiffness dependence on the number of cycles fatigue

3.4. Strength and stiffness after fatigue and water aging

The application of a sinusoidal mechanical load on a material generates damage. This last increases with the number of fatigue cycles involving an increase in the quantity of water absorbed by the material. The rate of saturation in a composite material depends on the intensity of the stress, of the direction of the request compared to the reinforcement, the chemical nature of the resin and the temperature of the medium of absorption.



a



b

Fig. 7 Static test results after fatigue with 10,000 cycles and aging: a) glass fibers laminate, b) Kevlar fibers laminate

After fatigue tests with various numbers of cycles, the test-specimens were immersed to a tap water for three different periods of time, in order to make them undergo various levels of aging. Then they were tested in static tensile, e.g. Fig. 7 gives the static test results after fatigue to 10.000 cycles and for three durations of aging (100, 500, and 1000 hours). This figure presents the stress-strain curves for both materials. The analysis of these results shows that the behaviour remains quasilinear until the specimen rupture, which is of fragile type. The ultimate stress and strain decrease when the time of immersion increases.

The results obtained in static test after fatigue and aging are presented in a semilogarithmic scale in Fig. 8, and Fig. 9. Fig. 8 represents the evolution of the residual strength according to the number of fatigue cycles n in both materials and for various durations of aging. In the same way, Fig. 9 gives the evolution of the residual stiffness obtained in static tests according to the number of fatigue cycles in both materials and for the various durations of aging. It could be noted also that strength (Fig. 8) and stiffness (Fig. 9) decrease when the number of fatigue cycles increase.

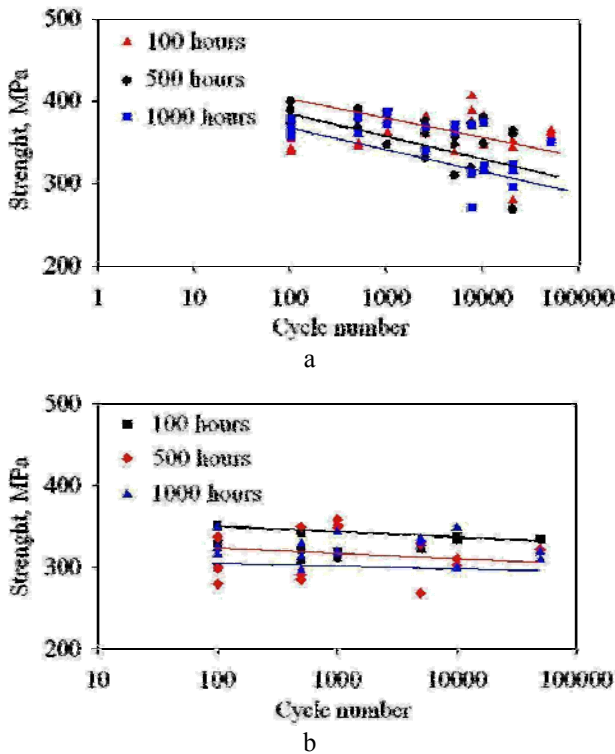


Fig. 8 Residual strength according to the number of fatigue cycles for the three duration of immersion: a) glass fibers laminate, b) Kevlar fibers laminate

These results highlight the effect of the damage by fatigue and the duration of aging on the behaviour of studied composite materials. The degradation of both materials depends on the number of fatigue cycles applied and the time of immersion. The rate of absorption of water is strongly influenced by the level of damage and water absorption clearly involves the reduction of strength and stiffness. The low interfacial resistance of composite materials to the aggression due to the absorption of water se-

verely compromises the advantage of using a matrix practically insensitive for humidity [13].

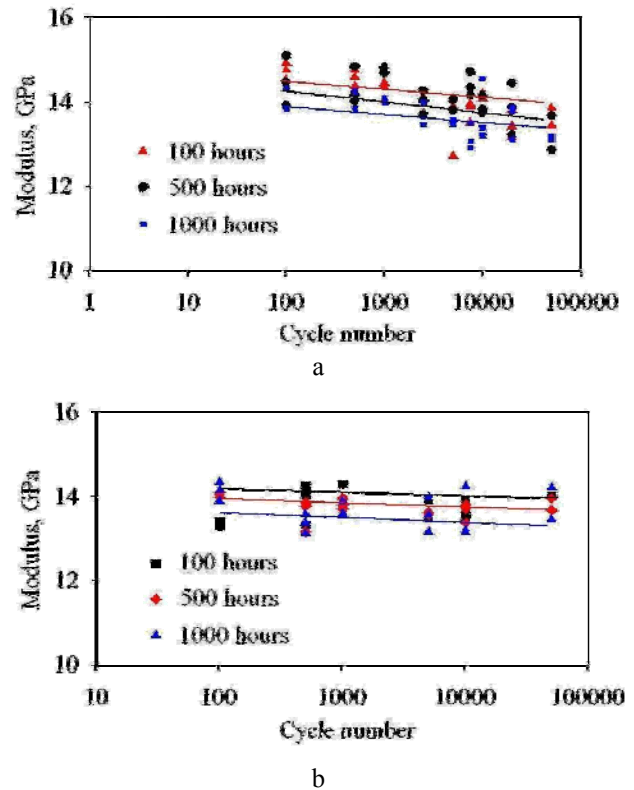


Fig. 9 Residual stiffness according to the number of fatigue cycles for the three duration of immersion: a) glass fibers laminate, b) Kevlar fibers laminate

4. Conclusions

This work comprises a significant number of results concerning aging in tap water for the time of immersion going up to 1000 hours. The both studied materials (glass fibers and Kevlar fibers laminates) present similarities in the fatigue behaviour, but differ in tensile strength.

The knowledge and prediction of the fatigue behaviour of composite materials with organic matrix and Kevlar and glass fibers, aged in wet environment state, require thorough studies, since they depend on several parameters, in fact, the technique of implementation, environment of aging, the tests, etc.

The specimens subjected to the tap water, are more fragile than those which were preserved in the air. The difference in resistance of materials probably is due to the propagation of water in the capillary left after the traction tensile fatigue effect (chemical and physical aging).

The influence of tap water on both materials (glass and Kevlar fibers) appears by a clearer degradation in wet medium state than in dry medium state, and it is more aggressive with the Kevlar fibers than with glass fibers. The number of fatigue cycles applied has quite a visible effect on the resistance of composite materials.

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SENDINIMO VANDENYJE ĮTAKA STIKLO IR KEVLARO PLUOŠTO EPOKSIDINIŲ KOMPOZITŲ MECHANINĖMS SAVYBĖMS

R e z i ū m ė

Straipsnyje pateikiami kompozitų sendinimo vandenyje eksperimentinių tyrimų rezultatai. Eksperimentai atlikti tempiant išilgai sluoksnių kryžmai sluoksniuotus laminatus, sudarytus iš stiklo pluošto, Kevlaro pluošto ir epoksidinės dervos. Pirmajame etape, buvo tirtos jų me-

chaninės savybės statiškai ir cikliškai apkraunant kompozitus. Kompozitų mechaninių savybių kitimas buvo nustatomas nuovargio testais įvertinant jų standumo mažėjimą. Antrajame etape buvo nagrinėjama kompozitų hidroterminio sendinimo ir nuovargio defektų tarpusavio sąveika. Statiniai įtempiai ir liekamasis standumo kitimas buvo tirti statiškai bei cikliškai apkraunant bandinius, esant įvairiam ciklų skaičiui ir sendinant juos gėlame vandenyje

Y. Menail, A. El Mahi, M. Assarar, B. Redjel, A.Kondratas

THE EFFECTS OF WATER AGING ON THE MECHANICAL PROPERTIES OF GLASS-FIBER AND KEVLAR-FIBER EPOXY COMPOSITE MATERIALS

S u m m a r y

This paper presents the results of experimental investigations of composite materials on the effects of water aging. The experimental investigation was conducted under longitudinal tension for different cross-ply laminates constituted of glass fibers, Kevlar fibers and resin epoxy. Static and fatigue properties were investigated in the first stage. Stiffness degradation approach is used to study the mechanical behaviour of composite materials in fatigue tests. The interactions between hydrothermal aging and fatigue damage in composite were studied in the second stage. The static strength and residual stiffness were evaluated in static tests after fatigue of specimens at different cycle numbers and aged in tap water.

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ВЛИЯНИЕ ПРОЦЕССА СТАРЕНИЯ В ВОДЕ НА МЕХАНИЧЕСКИЕ СВОЙСТВА КОМПОЗИЦИОННЫХ МАТЕРИАЛОВ

Р е з ю м е

В статье представлены результаты экспериментальных исследований влияния процесса старения в воде на механические свойства композиционных материалов. Экспериментальные исследования проведены при продольном растяжении различных слоистых ламинатов, состоящих из стекловолокон, волокон Kevlar и эпоксидной смолы. В первом этапе исследований определены механические свойства композиционных материалов, не подвергавшихся процессу старения при статических и циклических нагрузках. Поведение композиционных материалов во время усталостных исследований определялось оценкой снижения их жесткости. Во втором этапе изучено влияние гидротермического старения на усталостные повреждения в композиционных материалах. Статическая прочность и изменение остаточной жесткости композиционных материалов, подвергшихся процессу старения в пресной воде, были определены при статических и циклических нагрузках.

Received March 03, 2009

Accepted April 17, 2009