ISSN 1392–1207. MECHANIKA. 2016 Volume 22(1): 14–18

Acoustic emission monitoring of damage mechanisms an aramid-epoxy composite after tensile fatigue and aging seawater

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crossref http://dx.doi.org/10.5755/j01.mech.22.1.12176

1. Introduction

The polymer matrix composite materials have gained much advance compared with metals due to their very competitive features and affordable costs depending on the consumer and the control of their development. Their application areas are extensive (aerospace, aeronautics, automotive, shipbuilding, oil industry, civil engineering, etc.) and are becoming increasingly ”innovative” every day [1]. The critical role of reinforcement is still based on the specific use of the material and their characteristics [2]. Aramid and carbon fibers, besides their specific properties and their relatively high costs, remain reserved in usage to particular fields. As for the glass fibers in various forms, they are widespread due to their value.

The choice of the material (fiber and resin) that depends on the application field, its life and cost of the raw material and the production method, has led researchers to maximally optimize the performance of these materials by simulations and practical researches in situ [3]. In the marine environment, if the composites of glass fibers are more or less controlled due to their very large use, the aramid fiber composites are not [4]. This prompted us to contribute through this research to better understand the effects of sea water on the 171 Kevlar.

The purpose of this article is to determine the effect of sea water on an epoxy- aramid composite simulated to fatigue in tensile for different numbers of cycles and then immersed for different times. The rupture of the plate after fatigue and aging was followed by acoustic emission, for a better understanding of different phenomena (debonding, delamination and fracture of matrix and fibers) that occur in the material during the various tests [5-7].

2. Materials and methods

For this study, we opted for an aramid-epoxy composite. The preparation of samples and the experimental design were conducted in the laboratory LAUM (Acoustics Laboratory of the University of Maine) Le Mans, France. The mixture prepared for the test pieces of our realization is based on epoxy SR 1500 associated with an amine hardener SD 2505 provided by Sicomin Composites. Aramid fibers are of Taffeta 171. The composite plates were prepared by hand lay-up; vacuum, for the so-called "bag" technique. The polymerization was carried out in an oven at 80°Cfor6h. The cutting is achieved by an articulated head saw with a diamond disk to give to 1 mm thick specimen, 20 mm wide and 200 mm long. Tensile tests were conducted on a universal hydraulic machine INSTRON brand Model 8516 equipped with a load cell of 100 kN, shown by Fig. 1. The control and data acquisition were carried out via computer to record the evolution of the stress in function of the deformation, Fig. 2, and the tests were performed at ambient temperature (15-25°C). The machine is driven with a constant speed. This speed was determined after a series of preliminary tests, which helped setting it to 1 mm/min for all sample types. The use of the same speed, regardless of the type of test, eliminates the effect of viscoelastic resins, when comparing results from different tests.

Fig. 1 Hydraulic machine INSTRON 8516

Monitoring and acoustic data acquisition, are done in parallel with the mechanical tests with other software to another computer.

Fig. 2 Acoustic data acquisition

The experimental protocol was carried out the following way (Fig. 3):

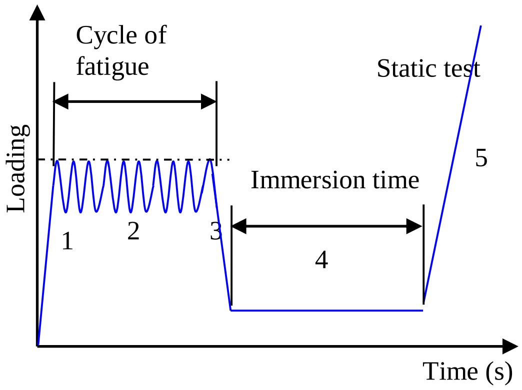

Fig. 3 Experimental protocol

* Loading at a constant speed of 1 mm/min under controlled displacement of up to 50% of the static rupture displacement.

* Fatigue with a form of sinusoidal waves, a frequency of 10Hz with an amplitude of 10% of the displacement at failure. We chose ten numbers of fatigue cycles ranging from 100 to 50,000 cycles.

* Unloading the specimen after fatigue.

* Aging in sea water for a period of 100 h, 500 h and 1000 h, as appropriate.

* Tensile strain with a moving speed of 1 mm/min.

3. Static tests

The results of the static tensile tests are given in Fig. 4 and the values are recorded in Table 1.

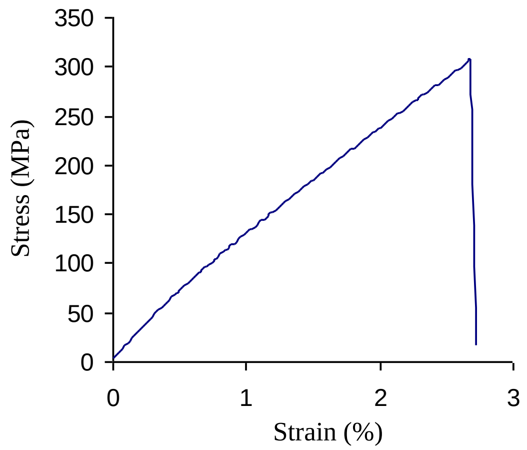

Fig. 4 Static test stress-strain diagram of Kevlar

Table 1

Static test results of Kevlar 171

Mechanical characteristics	Kevlar taffetas 171
Surface mass, g/m^2	170
Fiber, %	42
Longitudinal module, GPa	16.5
Transversal module, GPa	16.5
Stress of the rupture, MPa	305
Deformation of the rupture, %	2.7

The curve at the beginning of development and up to the maximum strain is characterized by a brittle-type behavior of the material, which is manifested by a substantially linear variation of the stress compared with the deformation [8].

This behavior is the result of the progressive disruption of the matrix; the weakest element of the composite, followed by debonding and possible delamination. Once weakened, the material fails due to stress, characterized by a sudden drop, which involves fiber breakage without arriving at the total failure of the specimen.

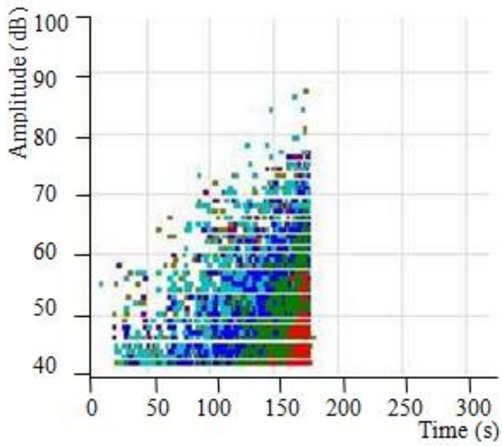

Fig. 5 Effect of traction on the composite

Fig. 5 illustrates changes in the effect of traction on the composite. The different mechanisms of damage encountered in this material are visualized through the acoustic emission and are mainly the matrix cracking, peeling at the fiber/matrix interface, the interlaminar delamination and final rupture of the fibers, which leads to degradation of the composite [9-11].

Each type of damage is characterized by its amplitude range. It is noteworthy that these different ranges are difficult to be identified accurately, since, from one side, they overlap each other and, on the other hand, the different authors do not give the same amplitudes for the same damage [12, 13].

In our case, it can be said that the matrix cracking starts from the first 25 seconds for a range between 40 and 60 dB. Debonding and delamination appear sporadically in the early solicitation to grow from 100 seconds (60-70 dB). As to fiber breakage it appears slightly together to increase the delamination late (70-85 dB).

4. Fatigue tests in tension

To determine the effect of fatigue on the material, we have opted for a series of numbers ranging between 100 and 50,000 cycles. Figure 6 gives an idea of the evolution of fatigue in a composite Kevlar 171.

The acoustic monitoring is a valuable contribution as it allows visualizing the different damage under gone by the material. To understand the emergence of different types of damage, it should be known that the specimen undergoes a load equal to 50% of the displacement at break static. Then fatigue starts at a frequency of 10 Hz, for an amplitude of 10% of the displacement at failure.

It is easy to distinguish the effects of both loading and fatigue. The first step occurs at the outset by a break in matrix followed by delamination and a fiber break, on a very short time which corresponds to sudden loading of the specimen. Then begins the fatigue manifested by a rupture of the matrix throughout the operation. Delamination is very low and the fiber breakage is very rare.

Following these results, we can say that the material has poor resistance to sudden efforts and adapts better to a long and constant fatigue.

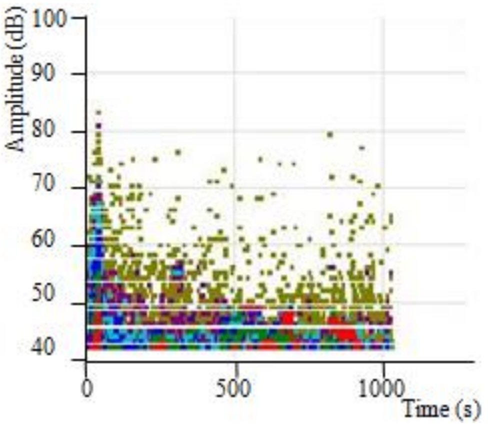

Fig. 6 Evolution of fatigue in Kevlar 171

As the material undergoes two successive stresses, fatigue then aging and their effects are superimposed. To distinguish them from one another, we conducted two series of tests. The first is a constant immersion (1000 h) and variation of the number of cycles for monitoring fatigue and constant fatigue (50 000 cycles) with variation of immersion for monitoring the aging periods.

5. Effects of fatigue

After different numbers of fatigue cycles (500, 1000, 10000 and 50000), the specimens are immersed in sea water for 1000h to undergo the same aging water. After that they undergo a static tension until failure. The obtained results, plotted on Fig. 7 are compared with each other to highlight the effect of fatigue on the aramid composite.

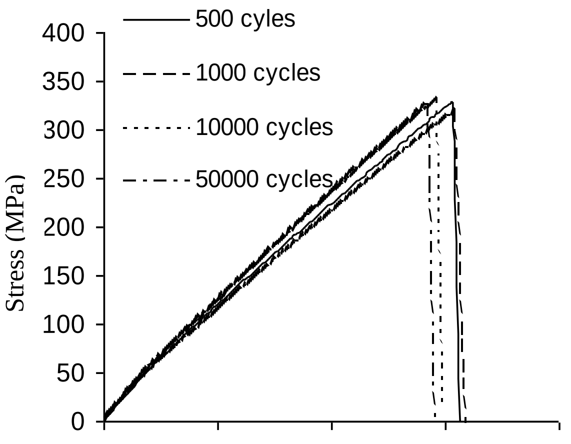

Fig. 7 Results of the static tests after fatigue and aging (1000 h)

They show that the behavior of the material is the same in the case of the static test of material characterization of the Fig. 4. It is of brittle type for the series of tested specimens. First, quasi-linear variations of the stress in function of the deformation, then a sudden drop in this latter. This drop is due to fiber rupture that causes the total failure of the specimen. We note that the maximum values of the stress and the corresponding stress decreases when the number of fatigue cycles increases, except for the curve 1000 cycles which is superimposed on that of the 500.We can deduce that the effect of fatigue is the same for the range 500-1000 cycles.

6. Aging effects

After different numbers of fatigue cycles, we immersed the samples in sea water for three different durations in order to subject them to different levels of aging. Then, they were tested in static tension. Fig. 8 shows the results of static tests after fatigue at 50,000 cycles and for the three aging times (100, 500 and 1000 h). This figure shows the evolution of the stress versus strain. The analysis of these results shows that the behavior is quasi-linear until failure of the specimen of brittle type [14-16].

The strain and displacement at the rupture decrease slightly when the immersion time increases, except for the 500 h. This shows that the immersion times must be increased so that monitoring becomes more representative.

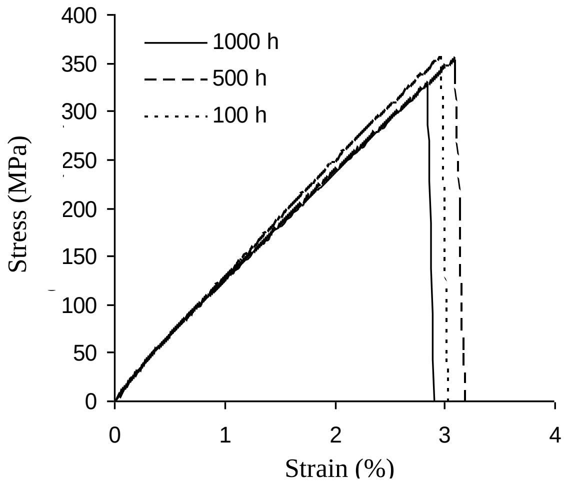

Fig. 8 Static test results after fatigue with 50 000 cycles and aging

7. Double effect: fatigue and aging

The effects of fatigue and aging are combined and shown in Fig. 9. This figure represents a static test after 1000 cycles of fatigue followed by immersion in sea water for 100 hours of 171 Kevlar compared to Fig. 4, which shows a static test without fatigue or aging. The results of Fig. 8 show that there are many changes occurring on the behavior of the specimen under the same test. The material is weakened because it begins to degrade from the first few seconds of the test, while the test piece of Fig. 4 begins to deteriorate only after the 25th second. Matrix rupture and sudden delamination appear due to the aging effects.

From the first 50 seconds, the various degradations begin to gradually appear intensively. From the 50th to 100th second, we notice a matrix rupture and delamination more or less diffuse. From the 100th to the end, we obtain a matrix rupture and delamination with more intensive development of fiber breakage.

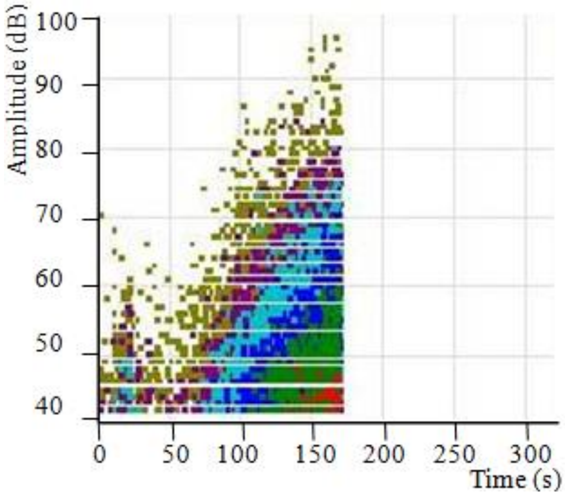

Fig. 9 Static test after 1000 cycles of fatigue followed by immersion in sea water for 100 hours

8. Conclusion

Although the objective of this work is more or less achieved, it has opened lots of opport unities that will allow us, if explored, to enhance our results and to better assimilate the various phenomena observed in this study.

The results of tensile tests in static and fatigue on an aramid epoxy-amine composite in a humic environment are convincing in most cases.

Knowledge and prediction of the behavior of these composite materials require more extensive studies, since they depend on several parameters, namely, implementation technique, testing themselves, the means of investigation etc.

The obtained results allowed us to notice that fatigue affects significantly the mechanical properties of the material, and the more the number of fatigue cycles is higher, the maximum load that can be support by the material decreases.

Similarly to the aging effect, the results have shown that the absorption of sea water by the composite affects negatively its mechanical behavior. The maximum load that the material can withstand decreases with the increase in the immersion time.

Hence, it can be said that the combination of two constraints only weakens the material, which was revealed by the acoustic monitoring. The emergence of various degradations, matrix rupture delamination and fiber breakage in the final phase, according to fatigue and aging is indicative of the behavior of this material and its characteristics.

Acknowledgements

It is my pleasure to take this opportunity to thank the director of LAUM Laboratory, University of Maine, for welcoming me into his structure, and to express my gratitude to the "composite materials" team leader for guiding me, and for everything he did to make this work successful.

I cannot end without thanking also the whole acoustic steam to which I have been introduced for the handling of the wonderful tool.

A thank you all!

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ACOUSTIC EMISSION MONITORING OF DAMAGE MECHANISMS AN ARAMID-EPOXY COMPOSITE AFTER TENSILE FATIGUE AND AGING SEAWATER

S u m m a r y

This paper helps to highlight the impact of tensile fatigue and hydric aging in sea water on a composite based the on aramid taffeta fibers and epoxy resin under acoustic monitoring. For this purpose, laminated test pieces were first stimulated to fatigue in several numbers of cycles (cycles 100-50000) before being immersed in the second place for several times (100 to 1000 h) in sea water (37%). The acoustic monitoring was conducted by three piezoelectric sensors were placed on the surfaces of the specimens during static tests. It allowed us to detect directly the different types of damage caused by fatigue and aging (matrix cracking, delamination and fiber breakage). The results that highlight the effects of fatigue and aging, show that these two parameters reduce the fracture characteristics of the material based on the progressively increasing number of cycles and increase the durations of immersions.

Keywords: Acoustic- Kevlar- fatigue- epoxy- seawater.

Received April 30, 2015
Accepted January 06, 2016