Hygrothermal and mechanical performance evaluation of glass-polyester composite for Renewable Marine Energies

M. Nachtane *[1,2], M.Tarfaoui[1], D.Saifaoui[2], K .Hilmi [3]
[1] ENSTA Bretagne, IRDL - FRE CNRS 3744, IRDL, F-29200 Brest, France
[2] Laboratory for Renewable Energy and Dynamic Systems, FSAC - UH2C, Morocco
[3] Institut National de Recherche Halieutique, Casablanca, Morocco
* mourad.nachtane@ensta-bretagne.fr
mostapha.tarfaoui@ensta-bretagne.fr

Abstract

Glass-polyester composites have promising application in the maritime domain, especially in the offshore energy industries due to their low cost, high strength-to-weight and stiffness-to-weight ratios, and corrosion resistance. Tidal turbines propose a new opportunity to use these materials to exploit ocean current flows to generate energy at locations with catastrophic loading. This investigation focuses on the Hygrothermal and mechanical performance evaluation of glass-polyester for renewable marine energy applications. The optimal design and the dynamic behavior of the turbine are studied. The hygrothermal effect and the hydrodynamic and hydrostatic pressures over the loading and the distribution of the stress, the deformation, and damaged zone under are presented.

Keywords: Renewable marine energy, Marine turbine, Composite materials, hygrothermal effect, Impact loading, Progressive damage**.**

I. Introduction

Composite materials are good candidates because offer new prospects for the renewable marine energy [1-2]. Inherently orthotropic, the nozzle can therefore be optimized to the loading, reducing weight, cost and improving efficiency of the turbine. Depending on their constituents, various types of tidal turbine were considered. An experience of composites in marine structures especially for offshore application was tested in [3]. This remains a topical subject a view of the complexity of the mechanisms of damage to the mechanical origin and environmental effect (temperature, humidity, residual constraints of implementation…) which can create irreversible damage preventing the satisfaction of the specifications in terms of performance. It is critical to control the evolution of the properties of the material in the course of aging, in order to predict the duration of life of composites. However, the variability of their behavior, especially under catastrophic environmental loading plays a major obstacle to further development [4].

Tidal turbines and their components will be directly in contact with sea water throughout their service life. This paper seeks to study of dynamic behavior of GRP marine current turbines and shown that ageing phenomena can reduce composite mechanical properties, and as a consequence reduce the lifetime of such structures. It is necessary to understand how sea water will diffuse into and act on glass/polyester materials in order to predict the lifetime of composite marine energy structures.

II. *The modelling of moisture absorption*

Water molecules will diffuse into polymer by activated jumps in the direction of the gradient concentration. we show basically diffusion processes in polymer materials, as presented in [5-6]:

- Fickian diffusion,
- Langmuir's diffusion

To predict the quantity of moisture absorbed in the composite materials before damage, the Law on Fick remains the most used because of its simplicity material, equation 1.

$$\frac{\partial C}{\partial t} = div(-D\overrightarrow{gradC}) \qquad (1)$$

With C the moisture concentration and D the diffusion coefficient of the medium. In our case, dissemination is unidirectional by consequence equation (1) becomes:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} \qquad (2)$$

Figure 1 represents the typical Fickian kinetics of diffusion obtained for a polymer; the water absorption is initially proportional to the square root of time and reaches a plateau value which represents the mass at saturation [7-8].

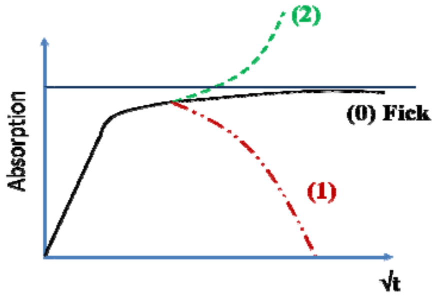


Figure 1 : Fickian kinetics of diffusion

Curve (0): Fickian behavior without damage.

Curve (1,2): A Hygrothermal damage is observable with kinetics of absorption.

To model this damage, we propose a model that is based on a variable solubility as a function of exposure time. It is assumed that the evolution of solubility is given by [5]:

$$S = S_0\, exp\left|\left(k\frac{t^* - t_s^*}{t_s^*}\right)\right| \qquad (3)$$

S_0 is the solubility of the moisture in the composite (concentration of saturation before damage).

t_s is the time threshold of beginning of the damage.

III. *Mechanical modelling*

The theories of damage have been developed and are heavily used in the Codes of commercial calculations to characterize the damage of composite materials [9-10]. They are based on a healthy initial state and the structure follows a law initial material of type orthotropic elastic or anisotropic. When the load in service of the structure reached a point of maximum operating, there is initiation of damage [11-12]. As soon when the behavior is changing and the damage grows up to total erosion of the element. The criterion of initiation the most currently used is the criterion of Hashin & Rotem and describes a damage plan in the ply:

- $F_{ft} = (\frac{\hat{\sigma}_{11}}{X^t})2 + \alpha(\frac{\hat{\sigma}_{12}}{S^L})^2 = 1 \quad (\hat{\sigma}_{11} \geq 0)$
- $F_{fc} = (\frac{\hat{\sigma}_{11}}{X^c})^2 = 1 \quad (\hat{\sigma}_{11} < 0)$
- $F_{mt} = (\frac{\hat{\sigma}_{22}}{Y^t})^2 + (\frac{\hat{\sigma}_{12}}{S^L})^2 = 1 \quad (\hat{\sigma}_{22} \geq 0)$
- $F_{mc} = (\frac{\hat{\sigma}_{11}}{X^c})^2 + \left[\left(\frac{Y^C}{2S^T}\right) - 1\right]\frac{\hat{\sigma}_{22}}{Y^C} + (\frac{\hat{\sigma}_{12}}{S^L})^2 = 1$

With α, coefficient of Rotem (0 < α < 1), the criteria of initiation, X_K, Y_K and S_K, the eligible in traction, compression, shear and $\hat{\sigma}$, the actual stress.

IV. Materials and properties

The materials used in this study are the ones taken directly from a real current turbine. They constitute of a Bi-axial fiberglass mat of 0.286 mm thickness in a Polyester resin matrix. The composite has been prepared using infusion process. The composite mechanical properties are given in Tables 1 and 2 [13].

ρ (t/mm^3)	1960 * 10^{-9}
E$_1$(MPa)	48160
E$_2$(MPa)= **E$_3$**(MPa)	11210
Nu$_{12}$	0,270
Nu$_{13}$= **Nu**$_{23}$	0,096
G$_{12}$(MPa)= **G$_{13}$**(MPa)	4420
G$_{23}$ (MPa)	9000

Table 1: Properties of glass-polyester composite

X$_t$(MPa)	1021,3
X$_c$(MPa)	978
Y$_t$(MPa)	29,5
Y$_c$(MPa)	171,8
S$_t$(MPa)= **S$_c$**(MPa)	35, 3

Table 2: Ultimate stresses of glass-polyester composite

V. Numerical simulation

A. Simulation of damage in marine turbine

Mechanical properties of turbine structures and damage initiation properties of specimens were listed in table 1. Many situations of accidental impact were treated in this work, Figure 2. We have made a parametric study to see the effect of the energy of the impact on our structure. Table 1 presents the different case.

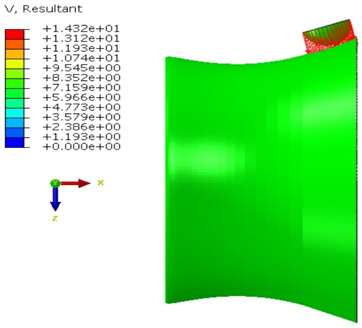
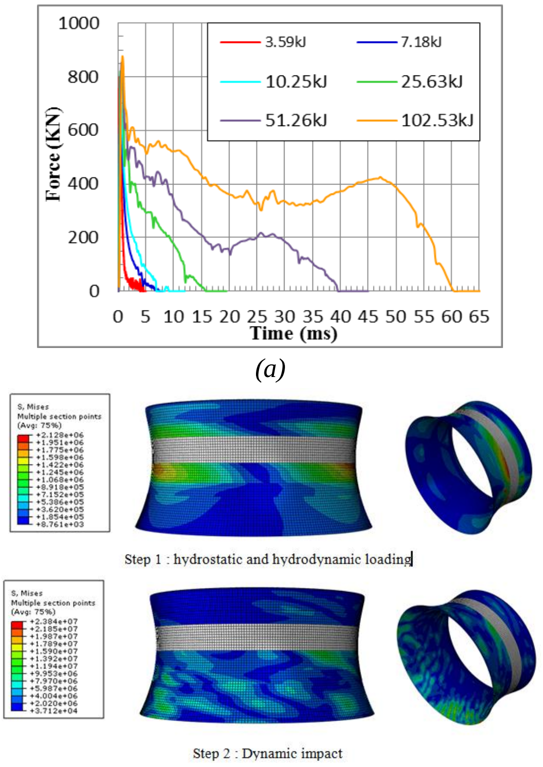


Figure 2 : overall system

V r (m/s)	M (kg)	E (kJ)
14,32	35	3,588592
14,32	70	7,177184
14,32	100	10,25312
14,32	250	25,6328
14,32	500	51,2656
14,32	1000	102,5312
14,32	1500	153,7968

Table 1. Accidental impact

Figure 3a show that the maximum force is obtained at higher velocity. Initially, the curve was linear and then became non-linear after the peak force due to initiation of damage, Figure 3b.



(b)

Figure 3 : Damage of the nozzle under hydrodynamic/hydrostatic loading followed by impact

B. Simulation of the Hygrothermal damage

The Finite Elements code Comsol Multiphysic was used to simulate the process of dissemination of moisture in the composite, before and after damage by integrating the model of damage (3).

In the marine environment, we can found a loss of mass. This type of damage is usually met when the matrix of the composite material loses these molecules during the phenomenon of exposure in the sea water. In this kinetics of moisture absorption, we have considered the model described by equation (1) and the settings Hygrothermal are summarized in:

- $D=0.9*10^{-6}$ s/m²
- C= 3 mol/m^3

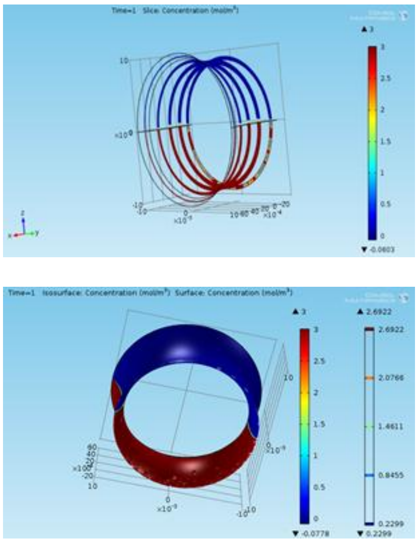


Figure 4 : Overview of the distribution of the concentration on the Tidal turbine

VI. Conclusion

In this work we coupled two software (Abaqus + Comsol) for modeling and simulating the dissemination of moisture and the damage due to the impact loading in the composite material before and after damage. In addition, the state of stress predicted can be important enough to initiate the mechanical damage which consequently will induce an aging hygrothermal observed numerically. The study presented briefly here has yielded several conclusions:

- The Performance of composites impacted in seawater depends heavily on the type of fiber, and especially of the matrix formulation.
- The Establishment of numerical models is a first step in integrating the response of the material in the design of marine energy recovery structures.

VII. Reference

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