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Research paper

Evaluation of durability of composite materials applied to renewable marine energy: Case of ducted tidal turbine

M. Nachtane [a,b,*], M. Tarfaoui [a], D. Saifaoui [b], A. El Moumen [a], O.H. Hassoon [c], H. Benyahia [a]

[a] ENSTA Bretagne, FRE CNRS 3744, IRDL, F-29200 Brest, France
[b] Laboratory for Renewable Energy and Dynamic Systems, FSAC - UH2C, Morocco
[c] University of technology, Iraq

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ABSTRACT

Composite materials are used in many marine structures such as renewable marine energy conversion systems because of their fairly good mechanical properties and especially their low densities compared to traditional materials. The most advanced features currently available in finite element (FE) Abaqus/Explicit have been employed to simulate the behavior of the composite nozzle under hydrodynamic and impact loading. A hydrodynamic analysis was considered to design the nozzle turbine and the hydrodynamic pressure obtained was then implemented as boundary conditions to a FE code. The goal of this article is to evaluate the durability of composite materials of a ducted tidal turbine under critical loads (hydrodynamic and hydrostatic pressures) with the implementation of a failure criterion using the finite element analysis (FEA). The mechanical behavior was analyzed for two materials (Carbon–epoxy/Glass–polyester). This has been accomplished by forming a user-created routine (VUMAT) and executing it in the ABAQUS software.

1. Introduction

Growing concern over the threat of global climate change has led to an increased interest in research and development of renewable energy technologies. Marine renewable energies can contribute to the diversification of the global energy mix because they have the advantage of providing a modular production (Mourad et al., 2018). In this context, composite materials will play a key role in this emerging industry because they have specific mechanical properties that are very remarkable in terms of reliability and durability (Smith, 1990). And because of its good experience in the marine environment and applications such as wind turbines and tidal turbines where they are subject to critical loads, very little information is available on their behavior in the water. However, the major disadvantage of using these materials is the mastery of the evolution of its mechanical properties due to the complexity of mechanisms of mechanical and environmental damage (temperature, pressure, humidity, etc.) which can create irreversible degradation preventing the performance specifications from being met (Davies and Lemoine, 1992). It is therefore essential to control the evolution of the properties of the material during its operation, in order to predict the lifetime of the composites.

Today, marine energy conversation systems such as marine current turbine that use the composite material that is currently the best way to achieve a balance between performance, weight and structural integrity because the marine environment is particularly demanding and aggressive: Salt corrosion, the forces of currents and storms (Boisseau et al., 2013). The advantage of glass reinforced polymer (GFRP) composites is that they are relatively inexpensive and offer sufficient strength and stiffness. The size of the turbines increases; the carbon fiber reinforced polymer (CFRP) becomes more popular for the development of certain parts such as blades and nozzle (Boisseau et al., 2012). Carbon fibers normally cost 10 to 20 times more than fiberglass. In fact, carbon fibers provide a much higher modulus and a significant weight reduction (Nachtane et al., 2016).

Tidal currents can provide a significant and predictable source of renewable energy. This work will research the use of composite materials for the nozzle of a tidal turbine to harness this energy. The rotor blades are currently made of steel, which leads to several problems in the marine environment, expensive manufacturing processes and difficulties in handling (due to weight). However, adequate strength and stiffness are needed for hydrokinetic and can alone is implemented by the utility of greater enforcement materials so as composite materials, beginning with a design which

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* Corresponding author at: Laboratory for Renewable Energy and Dynamic Systems, FSAC - UH2C, Morocco.

E-mail address: mourad.nachtane@ensta-bretagne.org (M. Nachtane).

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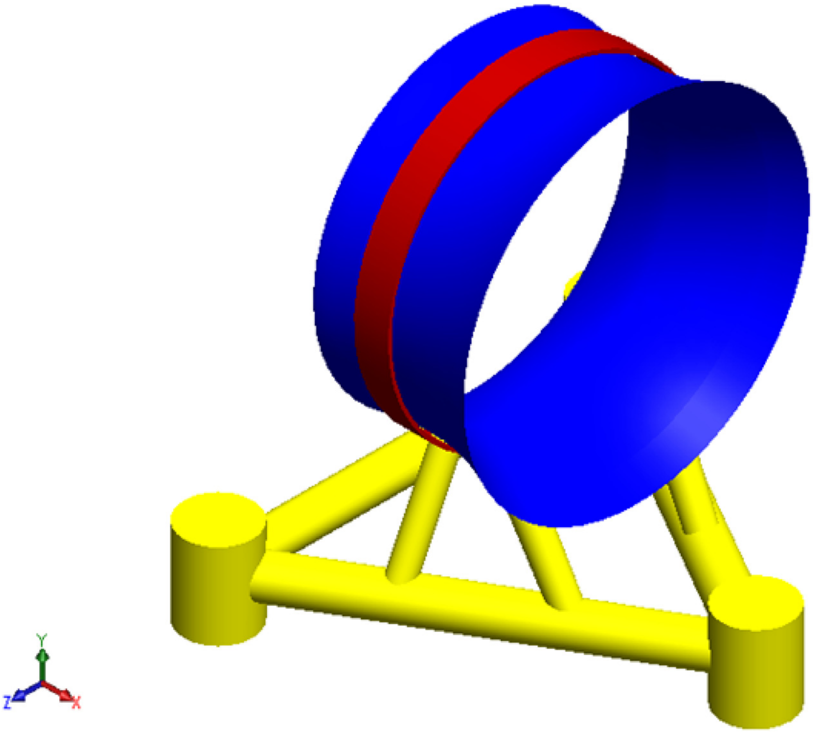

Fig. 1. 3D nozzle of the marine current turbine.

offers an accommodation between efficiency, endurance, weight, and cost.

This research presents a finite element analysis of the mechanical response of composite material applied to renewable marine energy. In order to meet the needs of the manufacturers of tidal current turbines, which is generally linked to a problem of mass gain, composite materials present a considerable asset on account of their excellent mass/rigidity relations. A structural design of ducted tidal current turbines using composite materials has therefore been examined. The duct of the tidal current turbine is especially confronted by the impacts due to its particular position. The impact damage aspect has also been examined in detail in the present research study.

2. Structure and mechanical properties of composites

2.1. Structure

Fig. 1 present the 3D nozzle of the marine current turbine considered in this investigation. We plotted the hydrodynamic profile using the Heliciel software. This structure is then included in the Abaqus finite element code in order to predict its behavior and mechanical performance.

2.2. Mechanical properties of composites

Ducted tidal turbine are routinely subjected to conditions of fatigue loading, which over time results in structural damage that negatively affects blade durability. Structural materials within a tidal turbine blade are therefore of considerable importance, and design parameters for such materials should be reviewed and optimized to decrease fatigue-related losses in strength and stiffness. The structural integrity of the nozzle depends on the combination of composites used to withstand the loads and the highest quality materials which are required for such marine applications.

The shipbuilding industry is dominated by fiberglass reinforced materials because of their mechanical performance and reasonable cost (Davies and Verbouwe, 2017). However, carbon fibers are more robust and lighter and their fatigue strength is much higher, however, there is very little data to describe their response induces many additional costs in manufacturing (Tarfaoui et al., 2017). In this research, we will use these two composite materials to make a comparison to know which of the two materials meets our expectations and industrial requirements. The structural design requires high material strength, high material stiffness, and low density (Nachtane et al., 2017). The composite mechanical properties for glass–polyester and carbon–epoxy are given in Tables 1 and 2.

Table 1
Properties of glass–polyester (Shah and Tarfaoui, 2014).

Properties	Value
ρ (kg/m^3)	1960
E_1 (GPa)	48, 16
E_2 (GPa) $= E_3$ (GPa)	11, 210
Nu_{12}	0, 270
$Nu_{13} = Nu_{23}$	0, 096
G_{12} (GPa) $= G_{13}$ (GPa)	4, 420
G_{23} (GPa)	9
X_t (GPa)	10, 213
X_c (GPa)	0, 978
Y_t (MPa)	29, 5
Y_c (MPa)	171, 8
S_t (MPa) $= S_c$ (MPa)	35, 3

The composites used are the ones taken directly from a real current turbine. They constitute of a Bi-axial fiber mat of 0.286 mm thickness in a resin matrix. The composite has been prepared using hand layup and cured under vacuum bagging under atmospheric pressure at room temperature. The composite lay-up used is symmetrical stack ply orientations [45/ −45/0/90/90/0/ −45/45].

3. Numerical model

The marine current turbine is the mechanical device that captures the kinetic energy of marine current to generate electrical