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Material Fracture of Dynamic VAWT Blade

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Abstract. In this paper we studied fracture and dynamic behavior of vertical axis wind turbine blade, the VAWT is a historical machine, it has many properties, structure, advantage, component to be able to produce the electricity. we modeled the blade design then imported to Abaqus software for analysis the modes shapes, frequencies, stress, strain, displacement and stress intensity factor SIF, after comparison we chose the idol material. Finally the CTS test of glass epoxy reinforced polymer plates to obtained the material fracture toughness Kc.

Keywords: Material · Blade · Crack · Frequency · SIF

1 Introduction

The renewable energy is necessary energy in our life modern, the wind turbine produce the electricity by wind force applied on the blade. In this study we define damage and fracture of Vertical Axis Wind Turbine blade. The air in motion relative to the surface of the earth, the differences in atmospheric temperature, pressure and density, which in turn initiate forces that move air from one place to another. Wind Turbine is rotating machine which converts the wind potential energy to electricity, we have two types, HAWT and VAWT, Horizontal Axis Wind Turbine (HAWT) is a turbine with a rotor is parallel to the ground, Vertical Axis Wind Turbine (VAWT) is a turbine with a rotor is normally to the ground, this last don't require yaw processes, lower start up velocities, localization on the rooftops, mesas, shafts located close to the grounds where wind velocities are lower, lower efficiency as compared to HAWT. The principals components of VAWT are shaft, Blade, Generator, Tower, Foundation. We have many manufacturing of VAWT. Blades is the surface through it by the wind to produce aerodynamic forces for turn the rotor, we have many types of blade: straight, helical and circular. Profile of Blade has many shapes like: Rectangular, Circular and NACA profile. The materials used in production of blade wind turbine has been resistive, cheeped, low weight, like this materials for example Wood, Aluminium, Composite. Aluminium material have light weight, low tensile strength, good reliability. PVC is very light weight. Composite material have good thermo-mechanical and chemical properties.

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2 Design of Blade

General information of blade helical wind turbine geometry Lecheb et al. (2015) (Table 1):

Table 1. Power as function a wind speed

V (m/s)	2	3	4	5	10
P (W)	3.279	11.067	26.233	51.237	409.9

Number of blade: 3
Power: 1–6 kW
Diameter of wind turbine: D = 1600 mm.
Higher of rotor: H = 2300 mm.
S_{swept} area = 1.9125 m^2.
Profile: NACA0015
C = 200 mm
ρ_{air} = 1225 kg/m^3
C_p = 0.35.

There are four various materials used for Wind Turbine Blades in this analysis:

1. Aluminium alloy blades.
2. GFRP blade.
3. CFRP blades.
4. PVC Polyvinyl Chloride blades.

Material properties of composite lamina shown in Table 2:

Table 2. Material properties of lamina composite

	Carbon/epoxy	Glass/epoxy
E_1 (GPa)	135	36.8
E_2 (Gpa)	9	8.27
V_{12}	0.3	0.21
G_{12} (Gpa)	5	4.14
G_{23} (Gpa)	5	4.14
G_{31} (Gpa)	8	4.14

3 Loads and Boundary Conditions

The blade is loaded by aerodynamic force (Fig. 1):

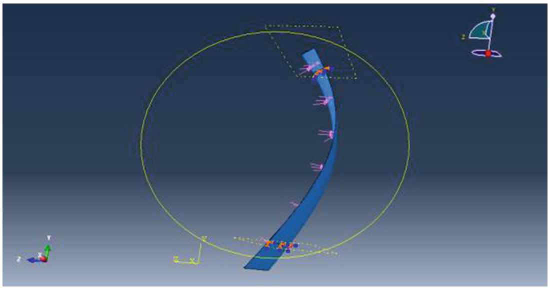

Fig. 1. Loads and boundary conditions picture

The mesh is obtained avec 11138 elements (Fig. 2):

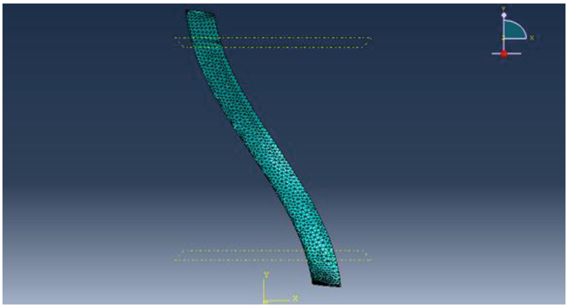

Fig. 2. Mesh of blade

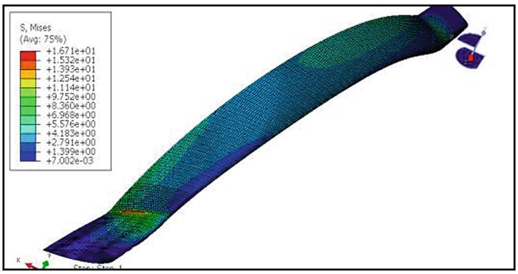

Fig. 3. Von Mises stress maximum S_{max} = 16.71 MPa

4 Results of Free GFRP

The Von Mises stress is obtained Lecheb et al. (2014) (Fig. 3):

Displacement (Fig. 4):

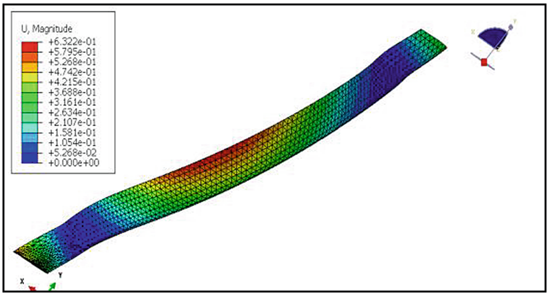

Fig. 4. Displacement maximum U_{max} = 6.322e−1 mm

We have shown first mode shape of blade and naturals frequencies Chellil et al. (2013) (Fig. 5):

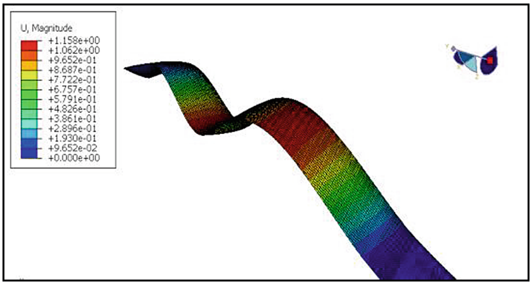

Fig. 5. First mode shape with f_1 = 80.917 Hz, U_{1max} = 1.15 mm

The static results are shown in Table 3:

Table 3. Static parameters of various materials blades

Materials	S_{max} (MPa)	E_{max}	U_{max} (mm)
Aluminium alloy	15.96	1.832e−4	2.373e−1
CFRP Laminate	16.23	8.906e−5	1.1e−1
GFRP Laminate	16.71	5.255e−4	6.286e−1
PVC	16.08	8.921e−3	11.16

5 Crack Propagation

After crack initiation, we increase the crack length between 10 to 50 mm, The results obtained shown in Fig. 6.

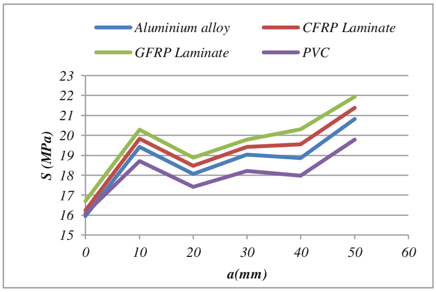

Fig. 6. Stress a function as crack size

6 Stress Intensity Factor

The equation of SIF is done by IRWIN:

$K1 = \sigma \text{ y } \sqrt{\pi}\text{a}$

In our case we have edge crack with factor of geometry correction is y = 1.12 and the curves are shown in Fig. 7.

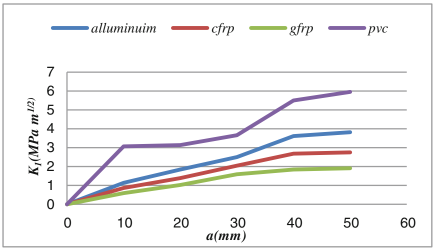

Fig. 7. SIF a function as crack size

7 Naturals Frequencies

The followings graphs present first six natural frequencies evolution as function a crack initiation of various materials (Figs. 8, 9, 10 and 11):

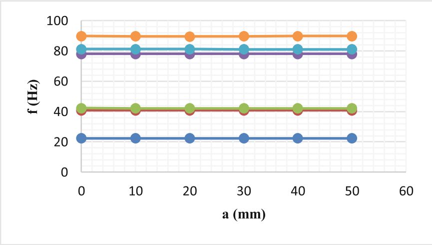

Fig. 8. Frequencies on function of crack size for PVC

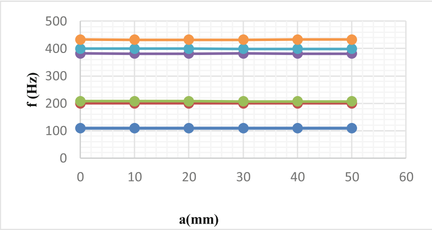

Fig. 9. Frequencies a function as crack size for aluminum alloy material

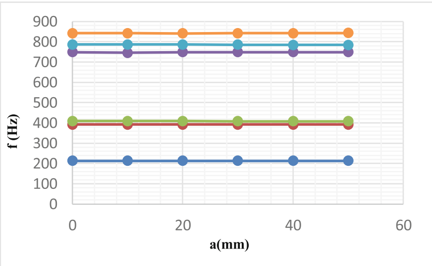

Fig. 10. Frequencies on function of crack size for CFRP

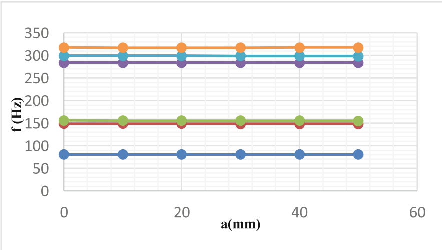

Fig. 11. Frequencies a function as crack size for GFRP

8 Experimental Study

In this experimental study we tested, calculation and compares experimentally the behavior results of the specimen of glass/epoxy cracked and un-crack then compared between the results obtained in the simulation. This result obtained by tensile machine (ZWICK ROELL 250 KN). So in our experiences we have cases to calculate (Fig. 12):

- Without crack in (glass/epoxy).
- With crack a = 5 mm and a = 10 mm.

Fig. 12. The specimen used in this test is plates of glass/epoxy (Mechakra et al. 2015)

Graph of the specimen with crack a = 5 mm (Fig. 13):

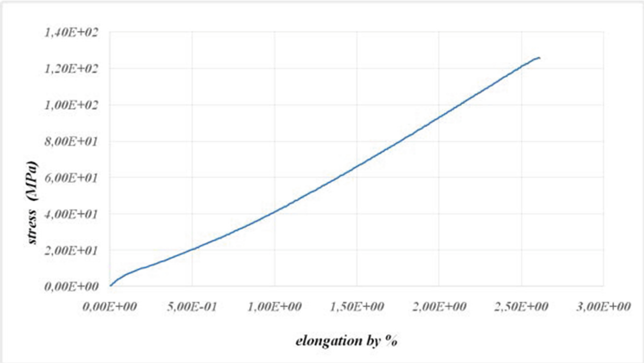

Fig. 13. Stress strain curve

This point of rupture has a pick value of stress which is S_{max} = 126 N/mm^2. In the experience of specimen with crack size a = 5 mm:

we have σy = 126 MPA and w = 25 mm:
$Y(CTS) = 5.26 + \alpha(5.22-5.88)/(1-(1.07 \times \alpha))$

$\alpha = a/w = 5/25 = 0.2$
$Y = 5.26 + 0.2 \times (5.16-5.88)/((1-(1.07 \times 0.2)) = 5.092$
$K_{IC} = 126 \times 5.092 \times \sqrt{(}0.005 \times 3.14) = 80.391\ \mathrm{MPa{*}m^{1/2}}$
$K_{IC} = 80.391\ \mathrm{MPa{*}m^{1/2}}$

9 Conclusion

In this study we were treated an example of application of the method FEM in 3D with several crack size and we compared the blade without and with crack. The vertical axis wind turbine is oldest machine, the vertical axis wind turbine have special component and many types. The composite materials are playing an important role in industry, it's very useful now. The frequencies increase on function of displacement in cases with crack and without it. The stress, strain and displacement increase proportionally with crack size in different materials. From this study the CFRP and GFRP are best materials use to produce blade of wind turbine. The experimental test the glass/epoxy with increase crack size. The result of Fracture toughness in numerical simulation is equal then in experimental test.

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