PRODUCTION AND MECHANICAL TESTING OF AN UNMANNED HELICOPTER TAIL CONE

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Abstract
One of the important structural parts of helicopters is tail cone which connects the tail rotor to the front structure which includes the main rotor. The tail rotor is an important part of a helicopter and is used to counter the torque effect created by the main rotor. Therefore, the tail cones are subjected to flexural and torsional moments. Because of the long distance between the main rotor and tail rotor, the lightweight materials such as composites are often used for the tail cones. In this study the tail cone is produced using carbon/epoxy face sheets and honeycomb core using a wet hand lay-up technique. The vacuum is applied during the production at elevated temperature. The tail cone is tested under bending and a combined loading including bending and torsion. The test of tail cone is also modeled using the finite element method. The experimental and numerical results are compared. The results are presented and discussed.

1 Introduction

Carbon fiber reinforced advanced composite materials are being used for several structural applications because of their mechanical properties, including high strength-to-weight and stiffness-to-weight ratios. The aerospace industry was among the first to realize the benefits of composite materials. Airplanes, rockets, and missiles all fly higher, faster, and farther with the help of composites [1]. One of the uses of these materials is for the tail cone of helicopters. The tail cones are the structures connecting the tail rotor to the fuselage. It is mainly subjected to the pitching moment and torsion. Because it is long to obtain the enough distance between the tail rotor and the main rotor, the materials used for manufacturing the tail cone need to be light [2]. Tail cone must provide structural support for the tail rotor, the fin and the tail plane, as well as having some aerodynamic characteristics. The cone has to be high set and slim to give clearance for the rear loading. The tail cone effectively couples two masses together; the main rotor and the tail rotor. These will each experience both static and dynamic forces. The main rotor will apply vibrations to the hull, but the tail rotor will tend to the lag behind because of its mass and it will result in stress on the tail cone. Whirling forces from the main rotor will rock the hull side to side. Helicopter tail cone must be resistant to bending and torsion [3].

Previous experimental studies showed that manufacture using honeycomb between two plies of carbon fibers is more available for composite helicopter tail cones. Therefore, in this study, an unmanned helicopter tail cone is produced using honeycomb between two plies of carbon fibers on each side. The tail cone is tested under bending and a combined loading including bending and torsion. The tail cone is also modeled by using the finite element method. Experimental and numerical results are compared.

2 Manufacturing and testing of tail cone

2.1 Production

The tail cone considered here is made of carbon/epoxy face sheets and a honeycomb core material. The tail cone is produced in three stages. In the first stage, the bidirectional carbon fabric and honeycomb are laid onto the mold which is in the semi-conical shape. Totally, four plies of carbon fiber and honeycomb are used for unmanned helicopter tail cone. The enough epoxy/hardener mixture is prepared. The mass ratio of the carbon fiber to the epoxy/hardener mixture is taken as one. So, 700 grams of epoxy/hardener mixture (500 grams of epoxy and 200 grams of hardener) is used for 700 grams of carbon fiber. The wax is applied on the mold to prevent the carbon fiber adhere to the mold. Then, two plies of carbon fiber are applied to the mold using the sufficient quantity of epoxy/hardener mixture. After that, the honeycomb is placed on the carbon fibers and then another two plies of carbon fiber are applied on the honeycomb. The carbon fiber, honeycomb and the mold are shown in Figure 1.

Figure 1. Production of tail cone by using hand lay-up technique.

The carbon fiber, honeycomb and the mold are placed in the vacuum bag. The pressure is set to 750 mbar and the mold is left for 24 hours at room temperature. The blanket is used to evenly distribute the vacuum. The process is shown in Figure 2.

Figure 2. The tail cone in the vacuum bag.

In the next stage, semi-conical structures, which are produced using hand lay-up technique, are properly cut with grinding machine. Two semi-conical shells after trimming are shown in Figure 3.

Figure 3. Semi-conical shells.

After that, composite tail cone is placed in the vacuum bag. These vacuum bags are both used for inner and outer sides. Therefore, the proper vacuum bags are prepared for both inner and outer sides. This process is the most difficult part of the production. Figure 4 shows that grounded side of the tail cone.

Figure 4. Grounded side of the tail cone.

Two-plies of carbon fiber tape band are applied with sufficient quantity of epoxy/hardener mixture at the inner and outer sides to connect the two semi conical shells. Tail cone is placed in two vacuum bags. Pressure is set to 750 mbar. At this stage, temperature is not applied on the tail cone. Figure 5 shows these vacuum bags.

Figure 5. Inner and outer vacuum bags.

After that, two plies of carbon fiber tape band are pulled from outside of the tail cone and the tail cone is put in the vacuum bag. Figure 6 shows inner tape bands after curing. Figure 7 shows outer tape bands after curing. The final weight of the tail cone is 1.5 kg.

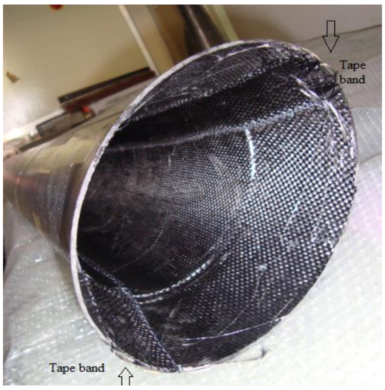

Figure 6. Inner tape band after curing.

Figure 7. Outer tape band after curing.

2.2. Testing

In this study, bidirectional carbon fiber is used for manufacturing an unmanned aerial vehicle. Mechanical properties of bidirectional carbon fiber and honeycomb are given in Table 1.

Mechanical Properties	**Bidirectional carbon fiber**	**Honeycomb**
E_x (MPa)	70000	50
E_y (MPa)	70000	50
E_z (MPa)	3000	50
ν_{xy}	0.3	0.4
ν_{yz}	0.4	0.4
ν_{xz}	0.4	0.4
G_{xy} (MPa)	10000	20
G_{yz} (MPa)	1000	20
G_{xz} (MPa)	1000	20

Table 1. Mechanical properties of composite materials.

The tail cone is tested using MTS universal testing machine. A special fixture is designed to connect the tail cone to a fixed frame to replicate the connection mechanism in the real helicopter. The tail cone and test fixture are shown in Figure 8.

Figure 8. Tail cone together with the test fixture.

The bending and torsional bending tests are performed by using displacement control and the reaction loads are measured. Both tests are repeated three times. The tests are shown in Figure 9.

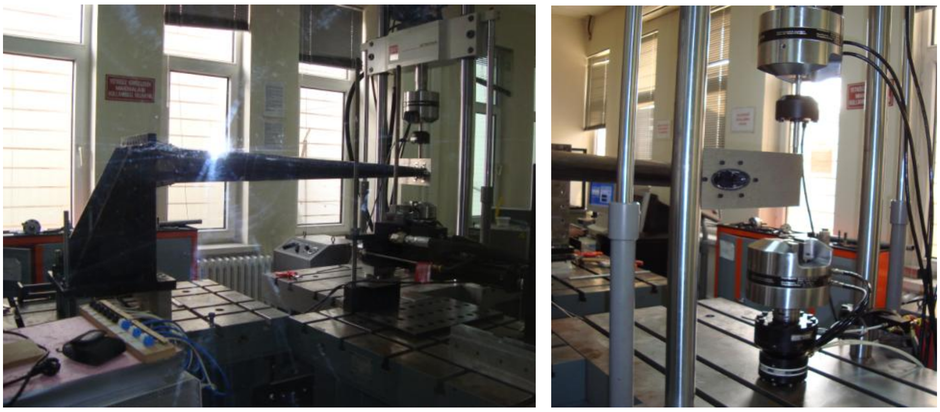

Figure 9. Bending and torsional bending tests.

3 Modeling and analysis of the tail cone

The tail cone and test fixture are modeled by using the ANSYS finite element software. The cone is modeled by using 17280 eight nodded layered shell elements (Sell 281) and the fixture is modeled using 128 shell elements [4]. The root is fixed and the displacement is given to the tip of the cone. The finite element model is shown in Figure 10. The static analyses are achieved and the displacement field and stress distribution are obtained.

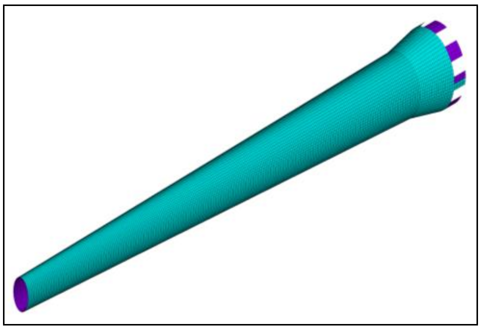

Figure 10. The finite element model of the tail cone and test fixture.

4 Results and discussion

The measured and computed reaction forces are shown in Table 1. It is shown that the reaction force is higher for the bending load compared to the torsional bending. This is because the torsional reaction moment is also contributing the load carrying in the case of torsional bending. The predicted reaction forces are found to be approximately 30% lower than the measured ones. The material properties used in the analysis could be a reason for this discrepancy. Also, the assumptions in modeling the boundary conditions could be a reason for the discrepancy.

Displacement (mm)	**Reaction Force Experimental (N)**	**Reaction Force Numerical (N)**
	Bending	Bending
5	143	102
10	292	204
15	438	306
20	575	408
	Torsional Bending	Torsional Bending
5	115	81
10	236	162
15	356	243
20	477	324

Table 2. Experimental and numerical results.

The displacement field is given in Figure 11. The Von Mises stresses are also given in Figure 12 for the displacement field shown in Figure 11. The maximum stress is found to be in the fixture at the root section as expected.

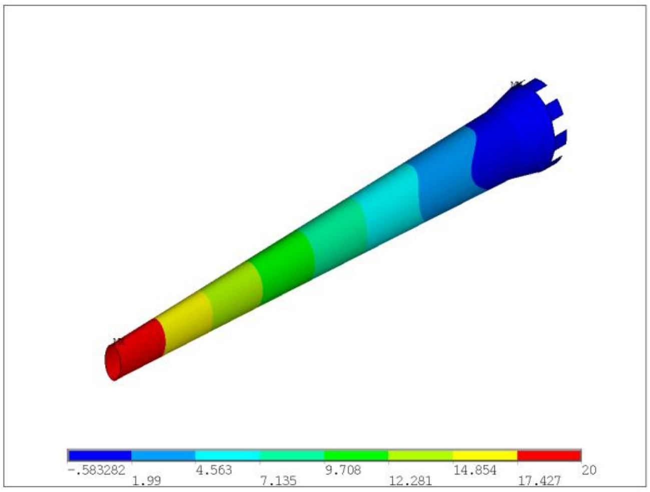

Figure 11. Displacement field of the bending analysis with 20 mm displacement applied at the tip of the tail cone.

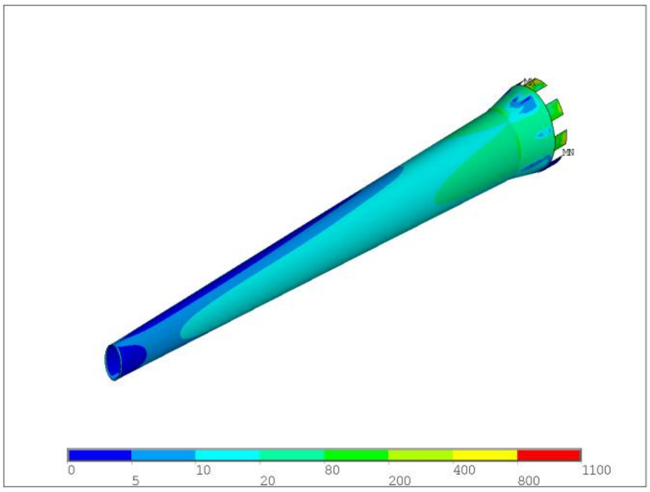

Figure 12. The Von Mises stresses for the 20 mm displacement applied at the tip of the tail cone (MPa).

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