DE-ICING OF CARBON COMPOSITE PLATES BY PIEZOELECTRIC ACTUATORS

L. Aretxabaleta*, M. Mateos, J.M. Abete, A. Aizpuru

Department of Mechanical Engineering and Industrial Manufacturing
Mondragon Unibertsitatea,
Loramendi 4, 20500, Mondragón, Spain
**e-mail:laretxabaleta@mondragon.edu*

Keywords: Carbon fibre composite, de-icing, piezoelectric actuators, vibrations.

Abstract

Ice creation on aircraft components may affect flight conditions and produce fatal effects. De-icing of these components can be carried out in several ways. One of these ways is to produce vibrations by using lightweight piezoelectric actuators. These actuators can excite the structures in their natural frequencies, resulting in the rupture of the weak adhesive shear bond of the ice-composite interface. The modes that produce maximum shear stresses in the interface are the ones to be excited, in order to obtain the most effective result. In this study, a simple cantilever carbon-epoxy plate has been analysed experimental and numerically. Different sized thick ice blocks have been generated on the surface of the plate. Vibration modes have been determined and the mode that produces maximum shear stresses has been obtained. The most effective excitation frequencies have been identified but the system is not capable of de-icing blocks situated in non optimal positions. Further investigations are needed to analyse the capability of the system to de-ice the composite plate.

1 Introduction

Ice creation in aircraft structures may affect flight conditions and produce fatal effects. Some of the accidents produced due to icing conditions are failure of engine components, stabilisers or wings. Aircraft wing icing related accidents occur due to the degradation in the aerodynamic performance or failure of the wing components, and in more than one half of the cases, icing was produced in the flying course and not due to an incomplete de-icing before taking off [1,2].

Icing mitigation systems result from two main strategies: Anti-icing and de-icing; anti-icing prevents ice to be created on a surface and de-icing removes the ice layers from the surface [3]. Both strategies can be divided into two methods: Passive and active. Passive methods take advantage of the physical properties of the blade surface to prevent or eliminate ice, and active methods use external systems that require energy sources (thermal, mechanical, pneumatic...).

Some active de-icing methods used are:

a) *Heating resistance*: An electrical heating element is embedded inside the membrane or laminated on the surface. It is simple but it needs a lot of energy and in extreme cases can be insufficient.

b) *Warm air and radiator*: This method is used as a prototype in wind turbines and consists in blowing warm air on the surface. This method also requires an important amount of energy.

c) *Ice breakage*: Ice can be broken due to impacts, vibrations, deformations or stresses produced by different methods. Some of these methods are pneumatic cylinders, ultra sonic systems [4,5] shape memory alloys (SMA) or piezo-electric actuators [6-8].

Among the different methods for removing ice, piezo-electric actuators have two main advantages:

- The actuators have very low power consumption, since energy is only used to excite the structure near a natural frequency; the vibrations produced at that frequency will be the origin of the interface breakage.

- Lightweight actuators can be located in the inner surface or even inside the material section [8] during the manufacturing process of the edge, without any variation of the airfoil surface.

The type of ice that can be produced in the atmosphere depends on several factors like temperature, humidity, pressure, wind speed, air density… each type of ice has different adhesion properties with a specific substrate, and adhesion strength can also be temperature dependent [9].

In this study, a simple cantilever carbon-epoxy plate has been analysed experimental and numerically. Different sized thick ice blocks have been generated on the surface of the plate. Vibration modes have been determined for both cases, and shear stresses have been obtained in the ice-composite interface; the most effective excitation frequencies have also been identified.

2 Materials and experimental techniques

2.1 Materials

A carbon-epoxy plate of 215 mm × 293 mm and 4 mm nominal thickness has been built by resin transfer moulding (RTM) technique. The fibre content of the plate is 58% and the nominal properties of the plate are shown in Table 1.

E_1 (GPa)	37.1
E_2 (GPa)	36.6
G_{12} (GPa)	12.7
ν_{12}	0.29
ρ (kg/m^3)	1610

Table 1. Nominal elastic properties of carbon/epoxy plates.

2.2 Experimental techniques

Two Mide Quick Pack QP10N Piezo-electric actuators have been bonded on the plate with the vacuum bag technique. Before bonding, the surface is cleaned with alcohol and positioning lines are drawn on the surface. A Teflon tape frame is put around the location of the actuators, and a chromate frame is put together with the aspiration tube, for the vacuum bag needed (Figure 1(a)). A Loctite Hysol® 9466 A&B bi-component adhesive is put on the location of the actuator, and the actuators are put on the adhesive surface; after that, actuators are protected by a Teflon sheet and everything is put under a vacuum bag (Figure 1(b)). Vacuum is applied at room temperature for 24 hours.

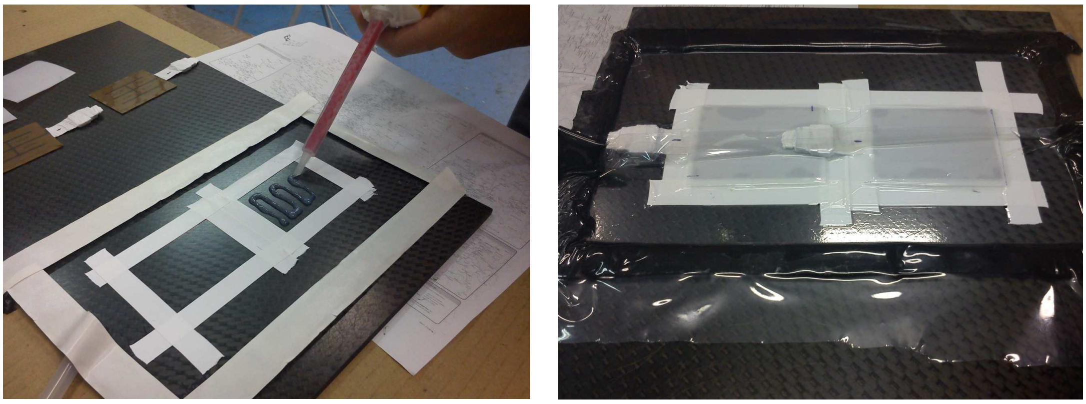

(a) (b)

Figure 1. Bonding of the actuators on the composite plate by the vacuum bag technique.

The plate has been anchored at one end in a metallic structure (Figure 2(a)) and the system needed for exciting the actuators has been mounted (Figure 2(b)), which is constituted of:

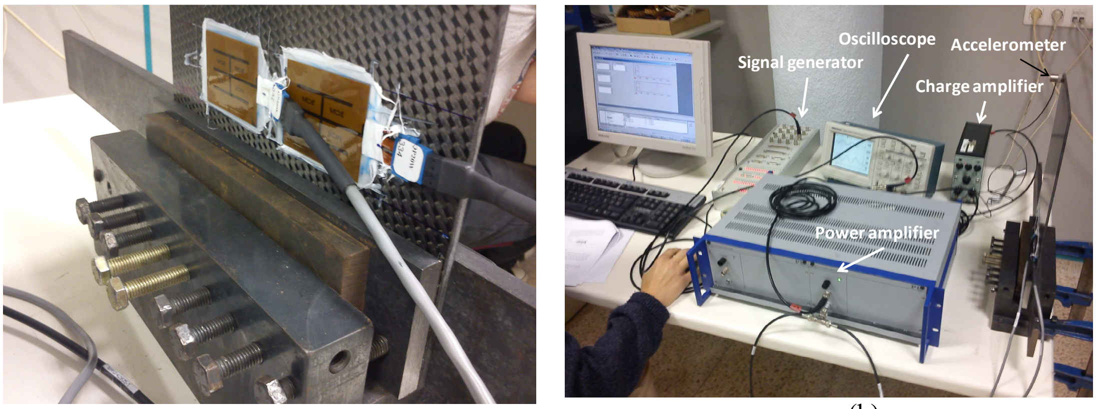
i) a dSpace DS1104 R&D signal generator controlled by Matlab/Simulink for generating signals at different rates.

ii) a power amplifier for amplifying the piezoelectric excitation signal.

iii) an accelerometer, for measuring natural frequencies.

iv) a charge amplifier for amplifying the accelerometer signal.

v) an oscilloscope, for monitoring the command and the real signals.



(a) (b)

Figure 2. Experimental tests configuration.

Ice has been generated on the surface of the plate in a conventional freezer, with an average temperature of -20º C. Rectangular ice blocks have been produced using a detachable mould that consists in four polypropylene square section beams covered by Teflon tape. Vertical pressure produced by grips is enough to maintain distilled water inside the mould without any leak during freezing process (Figure 3). Once ice is created, grips are removed and polypropylene mould parts are detached easily without breaking the interface between ice and composite.

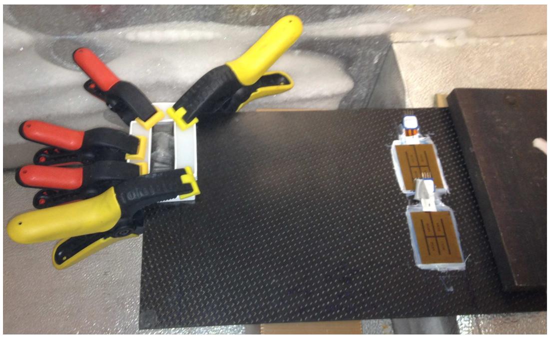


Figure 3. Ice generation on the composite surface.

Two ice configurations have been studied: one single 175 mm × 25 mm × 4 mm ice block centred at a distance of 20 mm from the free edge of the plate, and two 50 mm × 25 mm × 4 mm ice blocks centred at the same distance (Figure 4).

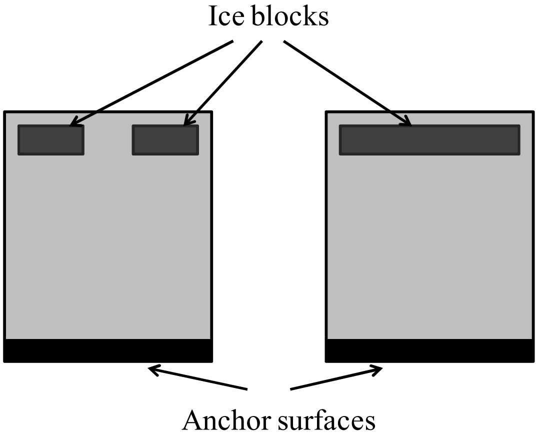


Figure 4. Different ice blocks configurations on the composite plate.

Experimental tests have been carried out at -15º C inside the freezer. The first eight natural frequencies of the plate have been identified and de-icing capabilities of the system have been analysed.

3 Finite element model

A cantilever plate has been modelled using shell elements in the finite element software Abaqus/standard. Anisotropic material properties equivalent to the whole layup (Table 1) have been defined for the plate; as out of plane shear modulus (G_{13} and G_{23}) must also be defined in the FE model, these have been estimated to be equal to the in-plane shear modulus G_{12}.

Ice blocks have been modelled as solid elements perfectly bonded to the composite surface. Ice elastic properties have been supposed to be isotropic, and are shown in Table 2 [10].

E (GPa)	9-11
ν_{12}	0.29-0,32
ρ (kg/m^3)	917

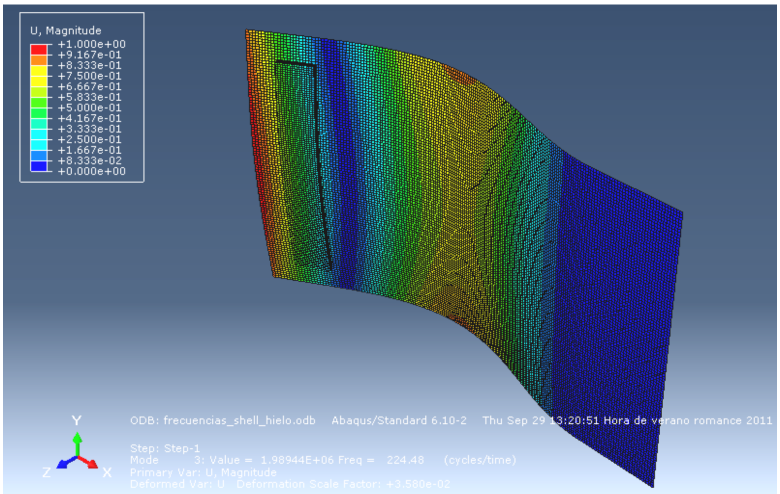
Table 2. Elastic properties of ice used in the FE model.

4 Results

The first eight natural frequencies of the plate with two ice blocks have been measured experimentally and numerically determined; results are shown in Table 3. It can be seen that there is a good agreement between both values. The shape of the 3rd mode is shown in Figure 5.

Mode	Experimental (Hz)	FE model (Hz)
1	33	35.524
2	105	107.09
3	213	220.53
4	353	369.18
5	479	473.65
6	594	625.73
7	738	766.24
8	810	777.23

Table 3: Comparison between natural frequencies measured experimentally and obtained by FE method.



```
ODB: frecuencias_shell_hielo.odb    Abaqus/Standard 6.10-2    Thu Sep 29 13:20:51 Hora de verano romance 2011

Step: Step-1
Mode        3: Value =  1.98944E+06 Freq =   224.48     (cycles/time)
Primary Var: U, Magnitude
Deformed Var: U   Deformation Scale Factor: +3.580e-02
```

Figure 5. Shape of the third mode obtained by FE method for the composite plate with a single ice block.

The third mode around 215 Hz has been identified to be the one that produces the highest shear stress in the ice-composite interface. Shear stress has been measured by two strain rosettes put on the composite surface in two different points (Figure 6). This measure has been performed out of the freezer without the ice block, but no major differences are expected in the frequencies due to the presence of ice.

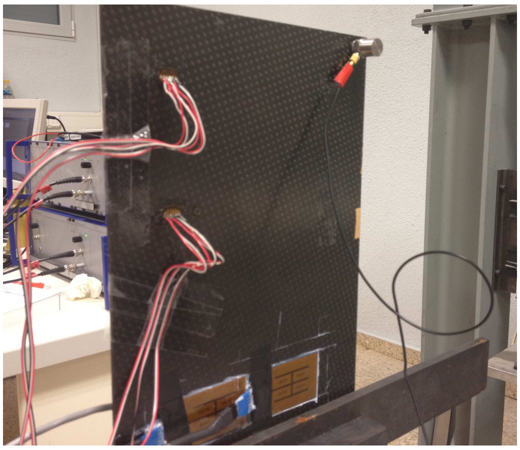


Figure 6: Strain rosettes for identifying the modes that produce the maximum shear stresses on the plate surface.

Experimental de-icing tests have been carried out to analyze the capability of the piezo-electric actuators to detach the ice blocks by exciting the plate at the natural frequency that produces the maximum inter-laminar stress between the plate and the ice-block. For these ice blocks positions, when the plate is exited at the third mode (or at any other mode among the first eight modes), the system is not able to detach the ice blocks.

Some additional tests have been carried out experimentally by putting ice blocks in a more adequate position for the third mode, and a longitudinal ice block has been cracked and partially detached immediately after connecting the actuators, as shown in figure 7. Further investigations are needed to validate this system and to analyze the optimal positioning of the actuators in order to detach ice produced in specific locations on a structure.

Figure 7. Cracked and semi-detached longitudinal ice-block.

5 Conclusions

The mode that produces maximum shear stresses has been obtained experimentally for a carbon-epoxy composite plate. The most effective excitation frequencies have been identified but the two-actuator system has not been capable of de-icing blocks situated in non optimal positions. Nevertheless, blocks situated in a more optimal position have been detached and cracked partially by the vibrations produced by the piezoelectric actuators. Further investigations are needed to analyse capability of a piezoelectric actuator de-icing system to be able to detach ice blocks in a real aircraft structure.

References

[1] Chen L. and Chang S. An Approach of AHP for Human Factors Analysis in the Aircraft Icing Accident. *Procedia Engineering,* **17**, pp. 63-69 (2011).

[2] Lampton A and Valasek John. Prediction of icing effects on the lateral/directional stability and control of light airplanes. *Aerospace Science and Technology*, Accepted 22 August (2011) (in press).

[3] Parent O. and Ilinca A. Anti-icing and de-icing techniques for wind turbines: Critical review. *Cold Regions Science and Technology*, **65**, pp. 88-96 (2011).

[4] Palacios J.L., Smith E.C. and Rose J.L. *Investigation of an Ultrasonic Ice Protection System for Helicopter Rotor Blades*, Proceedings of the American Helicopter Society 64th Annual Forum, Montreal, Canada, (2008).

[5] Palacios J.L., Smith E.C., Gao H. and Rose J.L. *Ultrasonic Shear Wave Anti-Icing System for Helicopter Rotor Blades*, Proceedings of the American Helicopter Society 62nd Annual Forum, Phoenix, USA, (2006).

[6] Venna S.V. *Development of self-actuated in-flight de-icing technology utilizing smart structure concepts*. University of Akron, USA,(2004).

[7] Venna S.V. and Lin Y.J. Mechatronic Development of a Self-Actuating In-Flight De-Icing Structures, *IEEE/ASME Transactions on Mechatronics*, **11 (5)**, 2006.

[8] Ghasemi-Nejhad M.N., Russ R. and Pourjalali S. Manufacturing and Testing of Active Composite Panels with Embedded Piezoelectric Sensors and Actuators. *Journal of Intelligent Material Systems and Structures,* **16**, pp. 319-333 (2005).

[9] Kraj A.G. and Bibeau L. Measurement method and results of ice adhesion force on the curved surface of a wind turbine blade. *Renewable Energy*, **35**, pp. 741-746 (2010).

[10] Zhang S., El Kerdi O., Khurram R.A. and Habashi W.G. *FEM analysis of in-flight ice break-up*, **57**, pp. 55-66 (2012).