Computation of thermal active composite structures

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Abstract

The CBCM is a thermal activated composite material. The thermal activation is made thanks to carbon yarns which are connected to a power supply. If the anisotropy of the structure is well organized, the desired deformation is reached when the temperature within the composite is rising. To obtain a morphing composite structure, a CBCM part can be locally incorporated in a classical composite structure. The first part of this work consists in presenting the experimental results for two examples of composite beams. The second part is about the FEM model (Abaqus software) and the different problems of non linearity which have to be taken into account.

Keywords: composite, smart materials, laminates, heat transfer

1. Introduction

The active structure concept deals with a continuous mechanical system. Then, it consists in integrating, within the material or the structure, some functions in order to reduce the number of joints and actuators. Among the various actuators, there are the piezoelectric materials. They are used in fibers form within a composite or in a patch form placed on the composite surface. The main application field is the vibration control, however particularly thanks to the development of MFC (Macro Fiber Composite) [7], some applications can be found in the field of shape control [2], or shape modification [6], by the used of bistable structures. Shape Memory Alloys (SMA) are other common actuators, but the bad cohesion between SMA yarns or sheet and the rest of the structure remains a problem [8]. This is particularly a disadvantage when the rigidity of the composite structure is high; the piezoelectric actuators encounter the same problem.

In order that the performances of the actuator are not limited by the structure rigidity, another solution is to use a part or the whole composite structure as an actuator; it is the CBCM principle (Controlled Behavior of Composite Material) [3], [4]. It is base on a bimetallic spring effect, and it works by using the anisotropic character of the thermo mechanical behaviour of the composite; then it just needs a variation in the temperature. There is two different ways to use the CBCM: the first one is called "temperature effect", the second is called "gradient effect". The differences between the two effects is the possibility for the composite structure to bend in one "temperature effect" or two "gradient effect" directions; in this last case, the deformation of the structure is controlled by the temperature gradient through the thickness of the composite structure. The temperature effect is obtained thanks to a laminate made of layers with different coefficients of thermal elongation in a given direction. To work as indicated before, the laminate has to be asymmetric. In contrast with it, the gradient effect can be obtained with any composite structure containing an insulating layer, for example a sandwich structure. If only one side of the composite is heated, the other side being insulated, a temperature gradient appears within the structure.

However, the thermal activation of a laminate plate (asymmetric or not) induces curves along the two dimensions of the plate. Then, if we want to get a maximal curve in one direction, it is necessary, not to rigidify the plate, to soften the curve in the other direction. Therefore, it is necessary to find a compromise between the longitudinal and the transversal thermal expansion coefficients of each layer of the laminate. A solution is to use a layer a low anisotropy, metallic for example [1].

The CBCM does not use metallic material (except for the electric connections), but only "natural" composite material, yarns of carbon (connected to a generator) are used by Joule effect to heat the structure. Two solutions can be considered to reduce the undesired curves.

To make an optimal choice, for the nature, the orientation and the placement of the different reinforcements. For a plate in bending (along its longitudinal axis), the addition, at the mean plan level, of a unidirectional carbon fabric in the direction of the transverse axis will soften the curve in this direction [4].

Increase the slenderness ration of the structure, or of the thermal activation area. In this way, thermal local activations have been already used for active assembly with integrated CBCM parts [5].

For the temperature and the bimetallic effect, the results shown that they can be located around the CBCM area. So the geometry of the CBCM area influences the bimetallic effect. The main objective of this work is to show that it will be possible to turn every non active composite structure into an active one without changing its initial geometry thanks to the used of a CBCM patch. In a first part, the composites beams and the experimental procedure will be described. The FEM procedure is presented in the second part and finally we will compare experiment results to the numerical ones.

2. Tested structures and experimental procedure

The tested beams (300mmx50mmx0.6mm) come from two different composite plates (400mmx400mmx1.4mm). The first plate (called TV) is made of three fiber glass balanced fabrics: the thickness of each layer is 0.2mm and their mass per unit area is 200g/m². The second plate (called UD) is made of two unidirectional fiber glass layers: the thickness of each layer is 0.7mm and their mass per unit area is 650g/m². In this last case, the beams are cut in order to have the UD axis along the transverse axis of the beams. The various layers of the plates have been chosen to have beams with different rigidities. Moreover, to put the unidirectional fibers along the transverse direction of the beam gives more importance to the matrix dilatation and then allows to have a maximal effect of the CBCM in the activation area. The matrix is an epoxy resin, Epolam 2025 from Axson; the process, and particularly the curing cycle is the one recommended by the manufacturer to obtain a temperature of glass transition of 135°C.

The local CBCM effect is created by adding an active composite patch (112mmx40mm) on the beams. The patch is made of two layers of balanced aramid fabrics (the thickness of each aramid layer is 0.35mm and their mass per unit area is 230g/m²). The active layer is made of four parallel carbon yarns and is located between the two aramid layers. The active patches are stuck on the beams by using a methacrylate resin (Adekit A320/400 from Axson). The use of an active patch, stuck on finished and cured beams, allows them to keep their initial geometry: it is no use curing the whole structure after the sticking operation. When the CBCM part is powered, two tests of cantilever bending are carried out. The first test consists in measuring the free deflection d_L using a Linear Variable Differential Transformer sensor (accuracy: 1/100mm), at 130mm from the clamping. The second test consists in locking the beam at 130mm from the clamping and measuring the available force (or blocking force F_b) at this point. This last test is performed on an universal test machine MTS 20 (from MTS®), and by using Testworks4 the MTS testing software (Load cell capacity : 10N, accuracy : 10^{-3}N). The temperatures on the CBCM area (T_{CBCM}), on the upper side of the plate beside the patch ($T_{upper\ side}$), and on its lower side ($T_{lower\ side}$) are measured thanks to thermocouples. A direct current is used to supply electricity to the CBCM.

3. FEM procedure and results

3.1. FEM procedure

Unsteady thermo-mechanical calculations using finite elements (Abaqus) has been performed on the two composites structures. The beam and the CBCM patch are modelized by two shells with tie conditions. An 8-node thermally coupled quadrilateral general thick shell element is used (S8RT, biquadratic displacement, bilinear temperature). The anisotropic thermo-mechanical behavior of each layer is obtained by an homogenized step and it is defined in locally anisotropic datum coordinate system, which follows the structure deformation. Thanks to the homogenized step the lost in rigidity versus the temperature for the matrix behavior is considered The Joule effect in the active layer is taken into account via an internal heating source ϕ (subroutine hetval). We have $\phi = P_e/(S_{ac}.e_{ac})$, S_{ac} and e_{ac} are respectively the area and the thickness of the patch area, and P_e is the electrical power supplied. For the active area, the assumption of a uniform heating is used, the power supplied in the active layer can be easily calculated by :

$$P_e = R(\sum_{j=1}^{n} i_n)^2$$

where R is the total resistance of the active layer, n is the number of active yarns and i_n is the current intensity in the yarn n. For the thermal problem, two heat exchanges are considered, convection and radiation.

3.2. Results

Free displacement and blocking force tests are computed. For the thermal problem, and by the use of the convection coefficients for each surface (upper and lower sides of the beam, upper side of the CBCM patch), the numerical results are fitting to experimental ones. The model of the blocking force needs to take in account the lost in rigidity of the matrix behaviour that is not the case for the free displacement model.

The final part of these numerical results is the study of the beam rigidity influence (Fig. 1). For different rigidities and for the same internal heating source ϕ, we have computed the free displacement and the gradient thought the thickness of the beam,$\nabla T = (T_I - T_{lower\ side})/e_B$, where T_i and $T_{lower\ side}$ are the compute temperatures respectively at the interface between the patch and the beam, and at the lower side of the beam. e_B is the thickness of the beam. The displacement and gradient values are normalized by the reference values (tested beams). The evolution of the free displacement versus rigidity is nonlinear and close to the evolution of the thermal gradient. The deformation of the composite is linking to the control of the thermal gradient thought its thickness. So the constitution of the active patch has to be well adapted to the one of the composite.

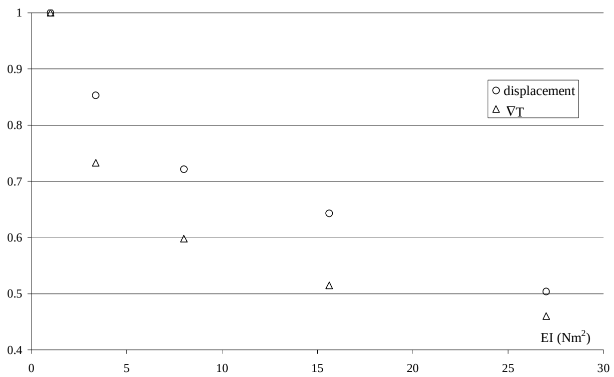

Figure 1: Evolution of the free displacement and thermal gradient (normalized value)

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