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SHAPE MEMORY COMPOSITES FOR SELF-DEPLOYABLE STRUCTURES IN AEROSPACE APPLICATIONS

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Abstract

Shape memory composites (SMCs) are attractive materials as they combine typical mechanical and functional properties of composites with shape memory properties. Such properties can be given to composite materials and structures by using shape memory polymer (SMP) matrices or integrating parts made of SMPs. In the case of integration, flexible composite skins can be applied over a shape memory foam core obtaining composite sandwich that can be shaped to change its stiffness or to reduce its volume. After the application of a given stimulus (generally by heating) the initial shape can be recovered. Future applications for this class of materials are self-deployable structures for space systems (such as actuators of solar sails or smart aerodynamic structures). In this work, two new SMC self-deployable structures were prototyped: a composite cross and a composite frame containing a thin aluminum sheet. The former structure represents a possible deploying configuration for a structural sheet whereas the latter is a conceptual study of a solar sail. The experimental results are very promising, showing that such structures can successfully self-deploy following the desired design constraints without noticeable damages. Finally, new perspectives for applications are highlighted

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Keywords: Shape Memory Composite (SMC); Self deployable structure.

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1. Introduction

The interest in shape memory polymers and composites is increasing for aerospace applications as light actuators, structural parts with reduced size during transport, and expandable/deployable structures [1]. This is mainly due to combination of mechanical and functional properties of the material with shape memory properties.

For heat activated SMPs, the shape memory effect is observed by performing a typical thermo-mechanical cycle [2]. Firstly, the polymer is processed to receive its permanent shape. Secondly, it is heated and deformed in a new configuration that can be stored by cooling. Heating up the stored sample above a transition temperature (which is the glass transition temperature, Tg, for thermoset polymers) it recovers its original shape. This concept has been also applied to open cellular (foam) structures and the presence of pores can magnify shape memory effects also in polymers with low memory properties. If fibers or particles are added to the SMP, shape memory properties can be reduced with the advantage of increasing strength and dimensional tolerance [3].

Interesting results have been found by using shape memory epoxy foams by solid state foaming [4]. By means of this new foaming technology it is possible to produce thermosetting foams by directly over-heating solid tablets of uncured resin [3, 4]. Composite foams can be obtained by mixing uncured resin powders and fillers, and pressing the mixture to make the tablets. MMT filled SMP epoxy foams have been studied and good results were obtained in terms of shape memory properties and structural properties [1, 3].

Shape memory properties can be also given to composite materials and structures by using shape memory polymers (SMPs) matrices or integrating parts made of SMPs [5-7]. Some examples are reported in [5] where shape memory composite tubes and plates were fabricated by adding a shape memory layer between two carbon fibre reinforced skins. An optimal adhesion between the different layers was achieved thanks to the compatibility of the prepreg matrix and the shape memory material. Shape memory composite structures were also produced by joining composite shells with shape memory foams. Some mechanical, dynamic mechanical and shape recovery tests were performed to show the properties of such materials and structures. Results confirmed the ability of this class of materials to easily change their shape without affecting the mechanical stiffness of the recovered structures.

Shape memory foam and composite laminate was also tested in a space mission on board the BION-M1 capsule through the Soyuz-2 launch vehicle with the aim to study its behavior in microgravity for future applications (Ribes_Foam2 Experiment, April 20, 2013) [8-9]. The experiment is the second in microgravity, and it follows the experiment IFOAM, Mission Shuttle STS-134 (May, 2011) [10-11].

Micro-gravity does not affect the ability of the laminate to recover its shape but it poses limits for the heating system design because of the difference in heat transfer on earth and on orbit. Moreover, it can affect the deployment in the case complex geometry. Experiment results have provided many useful information in particular for designing of a new structural composite actuator.

In this work, two new SMC self-deployable structures were prototyped: a composite cross and a composite frame containing a thin aluminum sheet. The former structure represents a possible deploying configuration for a structural sheet whereas the latter is a conceptual study of a solar sail. The experimental results are very promising, showing that such structures can successfully self-deploy.

2. Materials and methods

2.1. Composite structure production

Shape memory composite prototypes were produced by means of a sandwich structure. The outer skins were made of thermosetting carbon fibre reinforced (CFR) prepregs whereas the shape-memory interlayer was made of a thermosetting epoxy resin. Commercial materials were used for the experimentation. CFR prepreg (HexPly® M49/42%/200T2X2/CHS-3K by Hexcel) had a twill weave and a nominal epoxy resin content of 42 wt%, a nominal area weight of 200 g/m^2, and a thickness about 0.35 mm. This kind of prepreg is a 0/90 fabric typically used for aeronautical applications: the epoxy matrix shows high stiffness and strength without any shape memory behaviour.

In fact, shape memory properties depended on the interlayer made of an epoxy resin (3M Scotchkote 206 N) which was available as an uncured green powder, and was a one-part, heat curable, thermosetting epoxy coating.

Two main composite structures were prototyped: a composite cross (Fig.1a) and a composite frame (Fig.1b) containing a thin aluminium sheet (thickness of 100 µm). As above mentioned, the former structure could represent a possible deploying configuration for a structural sheet whereas the latter is a conceptual study of a solar sail. The size of the cross was 160x160 mm^2, the frame 200x200 mm^2. Both prototypes were formed by hot pressing in a hydro-pneumatic press (by ATS FAAR). The applied pressure was 1.3 MPa, the moulding temperature 150°C, and the holding time 15 min.

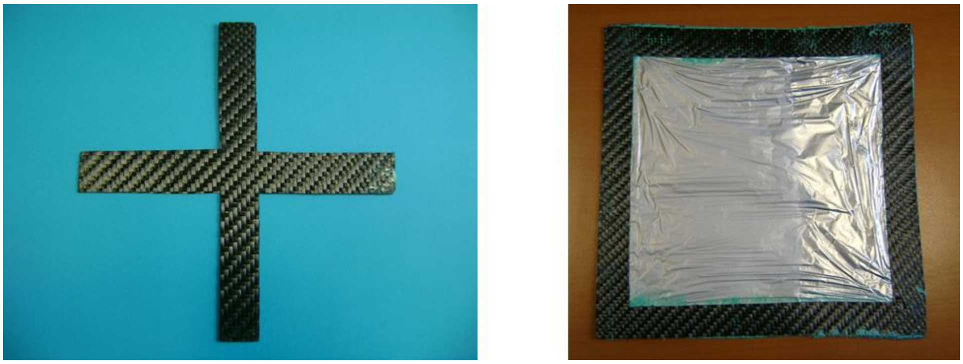

Fig. 1 Prototypes of composite structures: a) composite cross; b) composite fame.

A thermoplastic film was used for mould-release and was responsible for the wrinkles of the aluminium sheet (Fig.1b). After moulding, the prototypes were post cured in an oven at the temperature of 150°C for 1 hr.

In order to provide shape memory properties, prototypes were moulded by adding a SMP layer between two CFR skins. The production procedure was very easy as it was sufficient pouring the uncured SMP powder over a prepreg sheet (having the correct shape), and covering with another prepreg sheet. After moulding in the press and post-curing, the thickness of the SMP composite cross was about 0.9 mm and, therefore, the resulting thickness of the resin interlayer was about 0.3 mm. A similar resin interlayer was expected for the SMP composite frame even if an average thickness about 1.0 mm was measured. The difference in thickness between the two prototypes depended on the aluminium sheet which was partially intercalated between the composite skins of the frame.

2.2. Shape memory tests

Even if the behaviour of the SMC structures is quite complex because of the presence of two epoxy systems with different glass transitions temperatures, it has been observed that their transition ranges were comparable.

For this reason, 150°C has been considered as a good temperature for material deformation and recovery whereas higher temperatures could lead to degradation. Moreover, also in the soft state, the rigidity of the composites is expected to be high enough for bearing loads.

The shape recovery test for the SMP composite cross is shown in Figure 2.

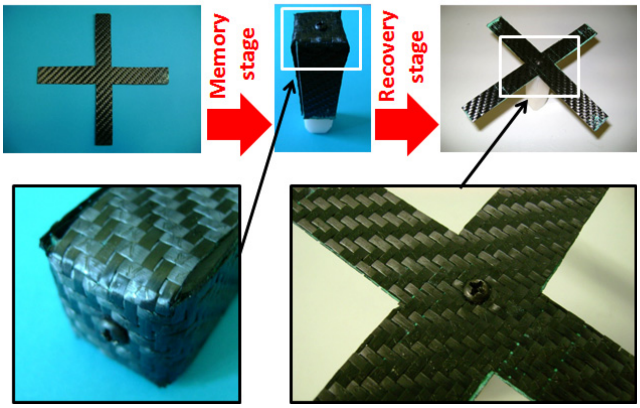

Fig. 2 Memory and recovery stage for the SMC cross.

It was fixed on a polyamide (PA) block with an height of 100 mm and a section of 20x20 mm^2, i.e. equal to the width of the cross arms. After heating, the memory stage consisted in a 90° rotation of the cross arms so as to put them in contact with the PA support.

The shape memory test of the SMP composite frame is reported in Figure 4. In this case a 3x3 folding operation was made, reducing the total area of the frame to 1/9 of the initial area. The aspect of the reduction of the total volume and so the sequence of folding is fundamental for the final deployment that is also function of the heating system. In particular, heating must promote the correct sequence of deployment avoiding the uncontrolled recovery of parts.

3. Results and discussion

Details of the recovery stage in oven are reported in Figure 3 for the cross of Figure 2. A time about 30 s was necessary for a full recovery and the composite stiffness was enough high also at the recovery temperature to guarantee the cross flatness. It is particularly important that damages or cracks in the bending zones or the surrounding areas were not found (Fig.2).

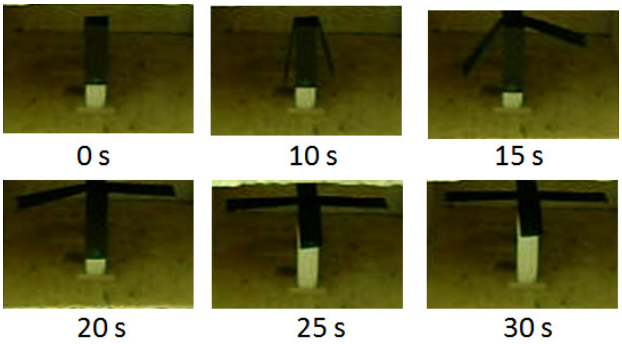

Fig. 3 Details of the cross recovery stage.

Figure 4 shows the results of the shape memory test of the SMP composite frame. Also in this case a good shape recovery was obtained in oven but some problems occurred because of the limited size of the chamber. Moreover, full planarity of the frame was not obtained probably due to frozen residual stresses during the composite production which were not eliminated by the post-curing stage.

It is interesting the deploying sequence shown at different time. After 120 s the recovery is practically complete.

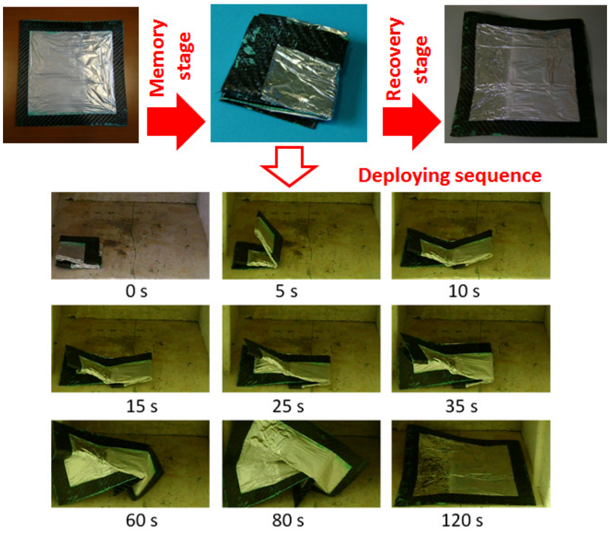

Fig. 4 Details of the shape memory test of the SMC frame.

These results are very useful for the development of possible deploying configurations for structural sheets or solar sails. Interesting applications could be systems for the capture of debris or for de-orbiting. These are existing and growing problem for space operations and for example the European Space Agency is currently undertaking a number of technology developments and studies within its specific programs [12]. For these purpose a correct design, specific experimental tests, and to enable potential mission to de-orbit a strategically chosen debris in the near future are necessary. Moreover, some aspects should be better investigated to deepen the present work such as the damage during and after the memory stage, the residual stiffness of the SMC, the final geometry to evaluate possible defects, etc.

4. Conclusions

In this study two SMC structures were prototyped to evaluate the deployment after the memory stage. The experimental results are very promising, showing that such structures can successfully self-deploy following the desired design constraints without noticeable damages. They are very useful for the development of deploying configurations for structural sheets or solar sails. Interesting applications could be systems for the capture of debris or for de-orbiting. For space applications, the effect of microgravity on complex and heavy structures will have to be subsequently examined because it can play a significant role in the deployment configuration. Material and geometry design is so fundamental to obtain such results, to avoid poor performance of the final SMC structure and for the success of the deployment. Several technological solutions are possible for SMC production and shaping, and the best solution has to be carefully evaluated depending on the single application and the expected properties.

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