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COMPOSITES
THEORY AND
PRACTICE

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MANUFACTURING COMPOSITE AILERON - CASE STUDY

The new generation of prepregs that can be cured without autoclaves, only with the help of vacuum bags and ovens, provide an excellent opportunity for small and medium sized private enterprises to manufacture high quality airframe parts. The design and manufacturing process of an aileron demonstrator made of an MTM46/CF0302 CF/epoxy prepreg, being one of the above mentioned vacuum bag curable ones, is presented. The aileron structure, its fabrication breakdown, the related inexpensive tools made of low thermal resistance polyurethane foam and the curing process allowing for the application of such materials are addressed.

Keywords: composite airframe, aileron, VBO prepreg, manufacturing

WYKONANIE LOTKI KOMPOZYTOWEJ - STUDIUM PRZYPADKU

Wśród preimpregnatów nowej generacji pojawiły się takie, które mogą być utwardzane poza autoklawem, jedynie z wykorzystaniem worków próżniowych i pieców. Eliminacja autoklawów znacznie obniża koszty inwestycyjne i w ten sposób oferuje małym i średnim zakładom o profilu lotniczym olbrzymią szansę na wytwarzanie kompozytowych elementów płatowca o parametrach mechanicznych umożliwiających kooperację z dużymi firmami lotniczymi. W artykule zaprezentowano demonstrator lotki wykonanej z preimpregnatu MTM46/CF0302, przystosowany do utwardzania poza autoklawem, i przedstawiono zwięzłą charakterystykę istotnych cech procesu utwardzania wymienionego preimpregnatu, rozwiązanie konstrukcyjne struktury demonstratora lotki wraz z dostosowanymi do niej podziałami fabrykacyjnymi, kolejność i sposób montażu oraz, związaną ze specyficznymi warunkami utwardzania wyrobu, koncepcję foremników i możliwy zakres ich wykorzystania. Proces utwardzania MTM46/CF0302 może być przeprowadzony w kilku wariantach. Jednym z nich jest proces dwuetapowy. W procesie tym wyrób zostaje wstępnie utwardzany w temp. 80°C w foremniku, następnie schładzany, wyjmowany z foremnika i dotwardzany w temperaturze 130°C poza foremnikiem. Proces taki umożliwia wykonanie foremników z taniej, łatwo obrabialnej i o stosunkowo niskiej odporności termicznej pianki poliuretanowej o dużej gęstości LAB975. Możliwość tę wykorzystano, wykonując z niej większość foremników potrzebnych do uformowania struktury demonstratora lotki, składającej się z dzielonych żeber, dźwigara głównego i pomocniczego, krawędzi natarcia oraz powłok o częściowo przekładkowej strukturze, stanowiących górne i dolne pokrycie. Wszystkie elementy po wstępnym utwardzeniu w piankowych foremnikach zestawiono w foremniku powłoki górnej, pokrywając uprzednio przewidziane do połącznia powierzchnie klejem Hysol EA9394.2. Po utwardzeniu się kleju w temperaturze pokojowej demonstrator został wyjęty z foremnika i poddany ostatecznemu dotwardzaniu poza foremnikiem w temperaturze 130°C.

Słowa kluczowe: kompozytowy płatowiec, lotka, preimpregnat VBO, wykonanie

INTRODUCTION

During the last 50 years, tremendous progress in the application of composites in the airframes of large aircrafts has taken place (Fig. 1).

In the case of small airplanes and gliders, the application of composites has been even greater and reached almost 100%. There is a tremendous number of examples that could be provided. Here we can mention just a few of such products manufactured or designed in Poland: AOS-71 electric powered motor-glider, Orka or the Flaris jet plane currently under construction. In general, an advantage of composite parts over metallic ones consists in airframe weight reduction, simplification in manufacturing parts of complex stream line shapes and an increase in airframe integrity i.e. reducing the number of parts that must be assembled. Often, the replacement of metal components with composite ones is done gradually and starts with the simplest ones prognosticating meaningful improvement in aircraft performance. An aileron is a good example. Replacement of its metal structure with a composite one reduces its weight and increases the manoeuvrability of the aircraft due to a decrease in the inertia moment relative to the longitudinal axis of the aircraft. At the same time, the application of CF reinforcement increases the aileron torsional stiffness being one of the crucial requirements. The composite parts of general aviation airplanes used to be made, and some still are, with the help of the wet lay-up impregnation technique.

In general, such a technique does not allow for precise control of the reinforcement volume fraction and in addition, yields high porosity that lowers the mechanical properties of the laminate. Unlike what was just mentioned, the application of prepregs eliminates these shortcomings. However, the application of prepregs requires expensive autoclaves and tooling because a high pressure and temperature are needed to complete the curing. The related high investment cost effectively eliminated small and medium sized private companies from the circle of possible manufacturers of high quality airframe parts. In the last few years this situation has changed because of the availability of Vacuum Bag Only (VBO) prepregs which can be cured outside of autoclaves.

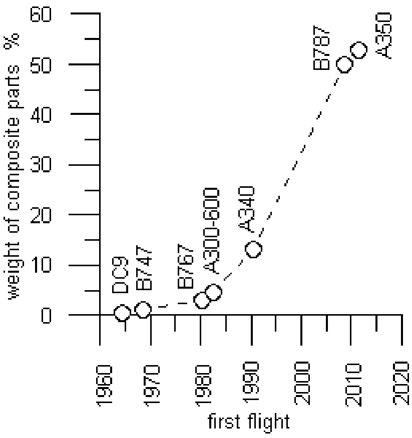

Fig. 1. Weight of composite parts expressed in percentage of total weight of airframe - trend

Rys. 1. Procentowy masowy udział elementów kompozytowych w strukturze płatowca na przestrzeni lat

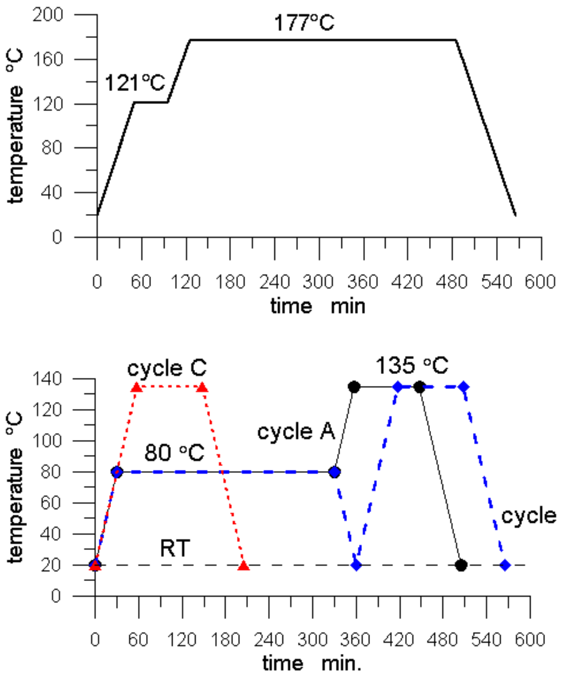

Fig. 2. Variants of curing process for MTM46 resin system (out-of-autoclave) and autoclave curing [1]

Rys. 2. Warianty procesu utwardzania pozaautoklawowego spoiwa MTM46 oraz autoklawowego

The essential differences in the curing process of traditional prepregs and VBO ones are shown in Figure 2. Due to new resin systems and the particular method of impregnation, it is possible to cure VBO prepregs at temperatures not exceeding 130°C and a pressure of about 0.09 MPa while autoclave cured prepregs require a cure temperature of 175°C and pressure of 0.8 MPa. As a consequence of the curing conditions of VBO prepregs, the required moulds can be made from inexpensive materials of low thermal resistance such as polyurethane foams of high density, e.g. LAB975 [2].

This paper focuses on the essential steps in the manufacturing process of an aileron demonstrator made of a VBO prepreg. Issues related to low cost tooling, alternative curing processes, fabrication breakdown, the assembly method and manufacture of the sandwich structure are addressed.

AILERON STRUCTURE

The structure of the aileron demonstrator is shown in Figure 3. The structure consists of upper and lower skins of a partial sandwich structure, nose and rear ribs, as well as the main and auxiliary spars. All the solid laminate parts are made from MTM46/CF0302 CF/epoxy prepregs. The fabric reinforcement denoted as CF0302 is of a 2x2 twill weave and areal weight 190 g/m^2.

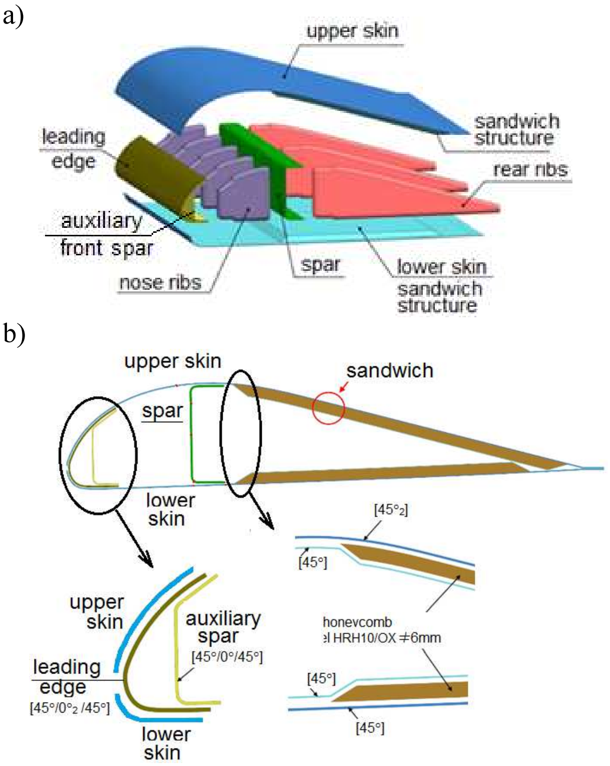

Fig. 3. Aileron structure: a) production breakdown, b) schematic representation of structure. Information given in degrees defines weft direction relative to longitudinal axis of part. Ribs of [45°$_3$] structure are not shown for clarity reasons

Rys. 3. Struktura lotki: a) podziały fabrykacyjne, b) schemat struktury. Żebra zostały usunięte z rysunku w celu poprawy jego przejrzystości

TOOLING

The two stage curing process of variant B (Fig. 2) requires an initial cure only at 80°C and allows for a consecutive free standing (out of mould) post-cure at 135°C. As a consequence, the application of a relatively low heat resistance material for the moulds is possible, e.g. high density polyurethane foam for which the working temperature is above 100°C, such as LAB975. This foam was used for the ribs, leading edge, spars and lower skin moulds (Fig 4) fabricated with the help of an NC milling machine.

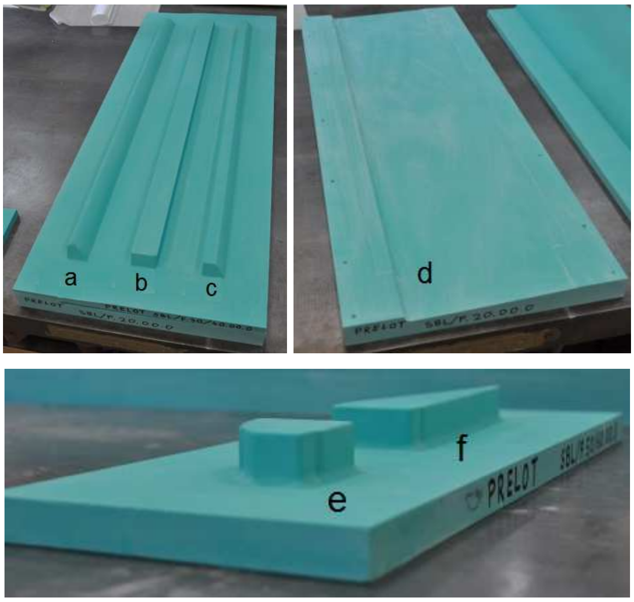

Fig. 4. Moulds made of high density polyurethane foam for: a) leading edge, b) spar, c) auxiliary spar, d) lower skin, e, f) ribs

Rys. 4. Foremniki wykonane z pianki poliuretanowej o dużej gęstości: a) krawędzi natarcia, b) dźwigara, c) dźwigara pomocniczego, d) dolnego pokrycia, e, f) żeber

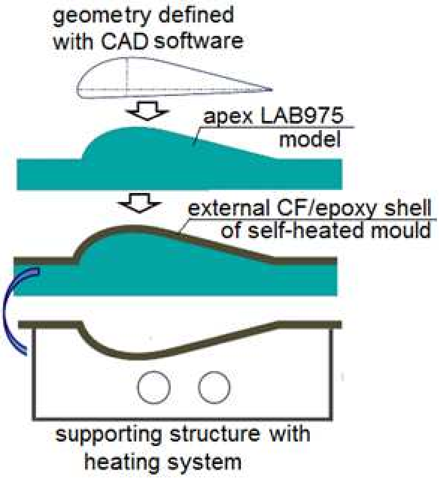

Fig. 5. Self-heated mould. Manufacturing concept

Rys. 5. Foremnik zespolony z systemem grzewczym. Koncepcja wykonania

The upper skin was cured with the help of a self-heated mould (Fig. 5), with a working surface made of CF/epoxy laminate. The detailed design of this mould is out of the scope of this paper and just brief information explaining the manufacturing concept is given in Figure 5.

MANUFACTURING PARTS

The ribs and spars were manufactured with solid laminates of the reinforcement configuration shown in Figure 3. The parts were formed with the help of apex (male) moulds. The application of such moulds allowed for avoiding concern about contaminating with a release agent the surfaces to be glued in the next step. The curing set-up is schematically shown in Figure 6. The parts were cured at 80°C (first step of curing process, Fig. 2). Fabrication of the upper and lower skins of the sandwich structure was more complicated. It involved gluing the honeycomb between two solid laminate faces. The MTM46/CF0302 prepreg is a net-resin content one and the tests revealed that the amount of resin squeezed out during debulking was not sufficient to form a proper adhesive joint between the core and laminate faces. Examples of typical failure modes are shown in Figure 7. It can be seen that only a negligible adhesive meniscus was formed and the produced bond was not of sufficient strength (Fig. 7b and d).

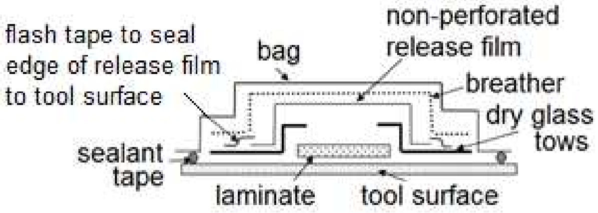

Fig. 6. Curing set-up

Rys. 6. Zestaw przygotowany do utwardzania

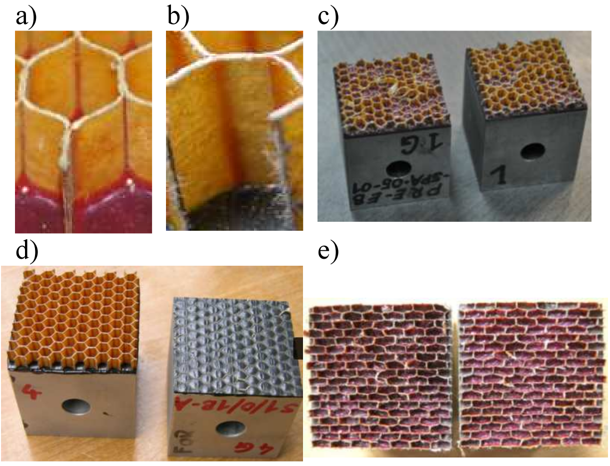

Fig. 7. Honeycomb-laminate adhesive joints: a) good and b) poor designs. Failure of c) good and d) poor honeycomb-laminate face adhesive joints; e) failure of honeycomb with rectangular cells

Rys. 7. Połączenie wypełniacz ulowy okładziny: a) dobre rozwiązanie, b) złe rozwiązanie. Zniszczenie połączenia: c) prawidłowe, d) nieprawidłowe, e) prawidłowe zniszczenie połączenia z wypełniaczem komórkowym o komórkach prostokątnych

For this reason, an additional adhesive film, Scotch Weld AF 163-2K [3] was applied. This resulted in improvement in joint strength and change of the failure mode to the correct one (Fig. 7c). The upper skin curvature forced the application of a rectangular cell honeycomb (Fig. 7e), since a typical one of hexagonal cells, if bent, takes the form of a saddle.

The manufacture of the honeycomb structure was competed in the following steps:

- manufacturing external laminate face
- shaping honeycomb core
- placing adhesive films on outer laminate face
- placing honeycomb core
- placing second adhesive film on top of the honeycomb core
- placing an appropriate number of prepregs on the top
- co-curing the set-up in vacuum bag at 80°C for 5 h

ASSEMBLING

All the parts to be assembled were initially cured at 80°C for 5 h. For assembly purposes adhesive paste Hysol EA93942 [4] was used which displays a shear strength of 11.3 MPa at 121°C, according to the data sheet.

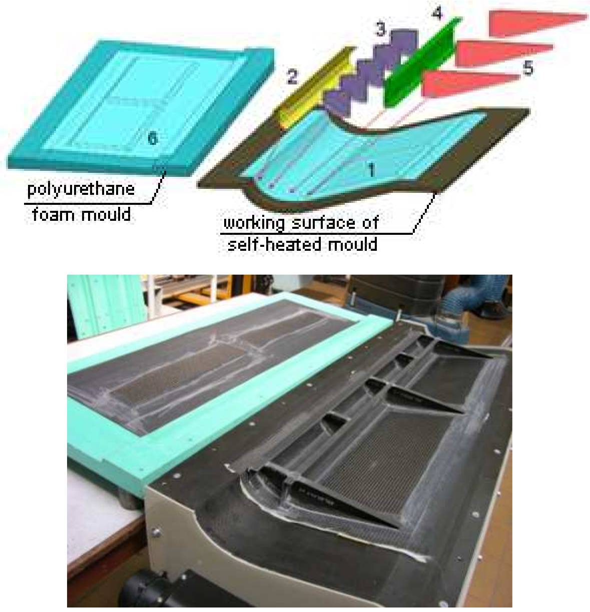

Fig. 8. Assembly sequence

Rys. 8. Kolejność montażu

For assembly purposes, the upper skin was left in the self-heated mould and the remaining parts were attached to it in the following order (Fig. 8):

1. leading edge with the auxiliary spar already glued into it (2)
2. front ribs (3)
3. main spar (4)
4. rear ribs (5)

Such a partially assembled structure was overlaid with the lower skin remaining in its mould (6).

Appropriate positioning of all the parts was achieved by marking their proper position on the free surface of the self-heated mould. The assembly was cured for 24 h at room temperature and then free standing post cured at 130°C for 2 h. The complete aileron demonstrator is shown in Figure 9.

Rys. 9. Kompletny demonstrator lotki wykonany z preimpregnatu utwardzanego w worku próżniowym, poza autoklawem

Fig. 9. Complete aileron demonstrator made of VBO prepreg

CONCLUSIONS

The possibility of manufacturing aircraft grade CF/epoxy structures from a VBO MTM46/CF0302 prepreg was demonstrated. It was shown that VBO prepregs allow for inexpensive tooling for which high density polyurethane foam can be used assuming a two-step curing process consisting in initial curing of the product in a polyurethane foam mould and final free standing post-curing.

Acknowledgement

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REFERENCES

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[2] Bloki obrabialne LAB 975, Axson Technologies.

[3] 3M Scotch-WeldTM Structural Adhesive Film AF 163-2.

[4] Hysol® EA 9394.2 Epoxy Paste Adhesive Henkel Corporation Aerospace Group.