**TRANSACTIONS OF THE INSTITUTE OF AVIATION**
**No. 1 (246)**, pp. 27-34, Warsaw 2017
DOI: 10.2478/tar-2017-0003
ISSN 0509-6669 eISSN 2300-5408

# PROCESS OF PREPARING AND LAYING CARBON PREPREGS

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**Abstract**

This article contains information on the technological process involved in the production of a composite structure with carbon-epoxy prepregs including critical parameters of the process. The information in the publication shows respectively:

1. Using composite components for constructing the airframe,
2. ways of storing and preserving carbon prepregs on a matrix of thermosetting resins,
3. specific types of varying weave fabrics used in the prepregs,
4. way of preparing material for the process,
5. cutting tools,
6. preparing swage,
7. list of the most popular materials, their characteristics, pros and cons of their applications,
8. issues related to types of release agent,
9. parameters of selecting release agents in the process of manufacturing structures with carbon prepregs,
10. process of laying plies in a layered structure,
11. defects which result from improper material laying in swage,
12. preparing the structure for heating and technical parameters of the process.

Keywords: carbon prepreg, composite material, release agents, swage

## 1. INTRODUCTION

During the second half of the 20th century, when carbon-epoxy composites began to be used to produce aircraft structures, they accounted for only 5% of airplane mass and were used exclusively as second tier structures. Today composites account for 50% of the mass of the plane (Fig. 1) and they include first tier structures like wings and elements of the fuselage.

Prepregs are composite materials, whose reinforcing fibers (both organic and inorganic) were impregnated beforehand by a thermoplastic or thermosetting weft, keeping the relative mass of both substances at an appropriate level. Prepregs can exist in the form of tape or fabric. Tapes of different widths are produced from glued together fibers running in parallel, from which layered structures of specified characteristics can be laid [2]. Fabrics are composed of at least two woven bundles: weft and warp. The type of weave used influences fabric rigidness, which in turn impacts the ease of laying [2]. Fabrics with a tighter weave have better mechanical properties, but are more difficult to lay. In the case of fabrics with a looser weave, laying complicated shapes in the swage is easier, but the mechanical properties of the created structures are lower than those of the former. Figure 2 shows the characteristic types of fiber weave.

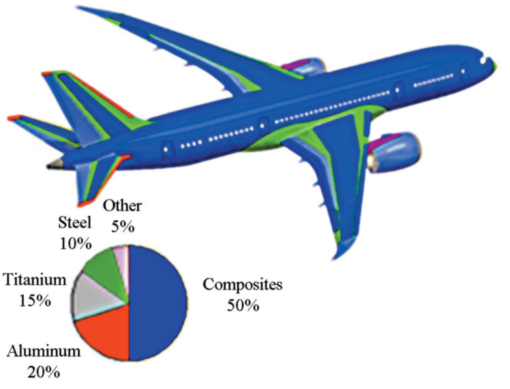


Fig. 1. Participation by weight of composites in the Boeing 787 Dreamliner airplane [1]

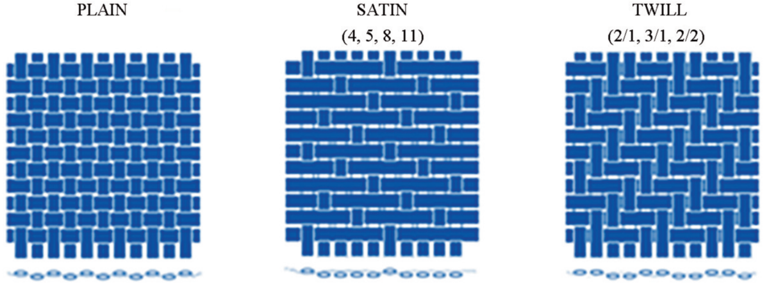


Fig. 2. Characteristic types of wave in fabrics used for prepregs [2]

## 2. THE PROCESS OF STORING AND TESTING PREPREGS

### 2.1. Storing

The main factor influencing the storage of carbon prepregs is the slow process of resin cross-linking in room temperature. It must be noted that storing prepregs in lower temperatures results only in the slowing of this chemical process [4]. This is the reason why prepregs are kept in cold storage, at a temperature of -18°C, in most cases no longer than for 12 months from the date of production [3]. The material can be used during a period of 30 days following its removal from cold storage. Prepregs must be stored in airtight plastic foil bags. All air should be removed from these bags, they must be hermetically sealed, and must contain a smaller bag for collecting moisture. After being removed from the freezer, the fabric should thaw in room temperature and in a humidity of 23÷30%. Thawing time is usually around 18÷24 hours. The thawing process is monitored by checking the prepreg's temperature when leaving the freezer and then a second time after 18±1 hours. The material can be removed from the plastic covering only once it has reached room temperature, that is 22÷24°C. Each thawing operation is recorded on control cards. This is essential, because of the fact that the process of cross-linking progresses during every thawing, which shortens the prepreg's expiration date [3].

## 2.2. Verification and cutting

We begin the verification of prepregs with the materials card. Above all else we need to check if the expiration date has not been exceeded. The next step is to verify the places where fiber displacement, lack of resin, etc. could have occurred. One of the producers (CYTEC) marks such places with characteristic color stickers (Fig. 3).


Fig. 3. CYTEC prepreg marking labels [Sokołowski, 2016]

The process of creating composite structures using carbon prepregs requires the use of precision material cutting. The basic tools used for cutting are (Fig. 4) various types of scissors, circular, straight, or curved cutting knives, etc. However, hand cutting is time consuming and imprecise. The main suppliers of composite structures, wishing to guarantee the repeatability of their products and to limit scrap waste, increasingly use cutting plotters for this task (Fig. 5). The quality of the forms is significantly higher, and the time needed for cutting is much shorter.

1. 2. 3.

Fig. 4. Cutting hand tools: 1 – scissors, 2 – straight cutter, 3 – circular cutter [5].

Fig. 5. Cutting plotter produced by ZUND company [6].

### 2.3. Preparation of the form surface

In order to achieve the desired form of the carbon prepreg composite, we must properly prepare the swage on which the material will be laid. Different swage shapes entail different solutions in their construction and in the material from which they were made. When assessing the technology to be used in the creation of a carbon prepreg element, two parameters must de defined:

1. From what material the swage will be made;
2. What will be the thermal cycles in the material hardening process.

Epoxy, invar, aluminum, polyurethane model sheets, are only some examples of the materials used in producing shaped forms. The factors influencing the choice of the appropriate material are:

1. Thermal expansion;
2. Possibility of tooling;
3. Type of surface on which the prepreg will be layed.

Table 1 shows some of the guidelines that are taken into consideration when selecting the material for swages. Each swage must be correctly designed and prepared.

Table 1. Basic factors in the choice of materials for swages [Sokołowski, 2016].

| Form material | Material cost | Tooling | Mass | Thermal expansion | Surface quality after tooling | Labor intensity |
|---|---|---|---|---|---|---|
| Polyurethane | □ | □ | ■ | ■ | ■ | □ |
| Epoxy | □ | □ | □ | □ | □ | ■ |
| Aluminum | ■ | ■ | ■ | ■ | □ | ■ |
| Invar | ■ | □ | ■ | □ | □ | □ |

where:
□ Favorable parameter
■ Unfavorable parameter

The preparation of swages on which carbon prepregs will be laid necessitates the laying of separation materials which will prevent the surface from adhering. The main considerations in the selection of anti-adhesive materials are:

1. Obtaining a large number of strippings;
2. Less applied product and thinner layer ;
3. Ease of stripping of complicated elements;
4. Obtaining a good appearance of the surface after the hardening process.

Wax is the most popular separation material. Its cost is very low compared to other popular protective solutions. It is easily accessible and its application time is short. The downside is the difficulty of applying it places with high curvature. In situations with right angles, the wax sticks in the corners and is very difficult to remove. In addition, wax has a low thermal resistance compared to products such as Frekote or Chem Trend.

The following systems are composed of several elements:

1. A mix of solvents used to clean forms of impurities or previously applied separation materials;
2. Underlay;
3. Sealant;
4. Layer of anti-adhesive material [7].

The intermediate layers serve two basic functions:

- They increase the effectiveness of the principal separation material;
- They allow for a larger number of strippings between successive applications of anti-adhesive liquids.

Table 2 shows the factors impacting the choice of the appropriate product:

Table 2. parameters of material selection [Sokołowski, 2016]

| Separation material | Accessibility | Application time | Ease of application | Thermal resistance |
|---|---|---|---|---|
| Frekote | | | | |
| Chem Trend | | | | |

where:
Favorable parameter
Unfavorable parameter

## 2.4. Laying of prepregs into a layered structure

The laying of composite sheets made of carbon prepregs into a layered structure is divided into flat and curved elements. Both tapes and fabrics can be used to create sheets with a vacuum table Fig. 6).

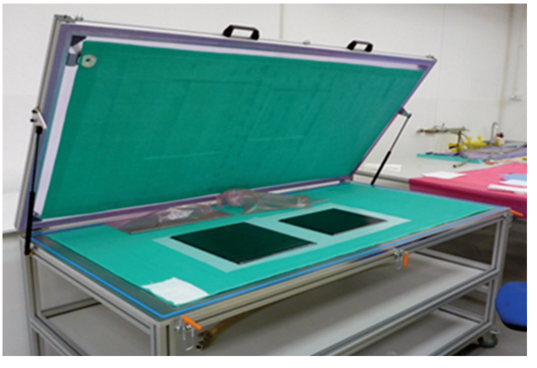

Fig. 6. Vacuum table [Sokołowski, 2016].

Vacuum allows the removal of excess air from between the different layers of the composite. The first layer of the prepreg should be vented for 10 minutes so that it adheres correctly to the swage's surface. Every following layer should be vented for at least 15 minutes. The use of the vacuum table increases work efficiency and assures the repeatability of the produced composite sheets.

The process of laying layered composites in forms with intricate shapes is more complicated. In this case it is advantageous to use fabric with a twill, satin weave. Thanks to the fibers being placed at a 45° angle, the fabric adapts better to the form of the swage than fabrics with other weaves would. Unfortunately this is not always possible. The most common defects related to the placement of the material in the form are:

1. The inflow of resin into the empty space between the swage and the insufficiently pressed material (Fig. 7-1);
2. Folding and shearing of the material in corners (Fig. 7-2);
3. Deformations caused by the insufficient pressing of the material into the form (Fig. 7-3).

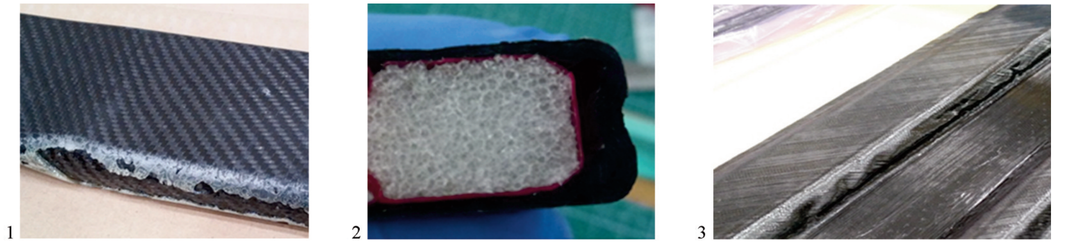


Fig. 7. Defects caused by the incorrect placing of the material in the form: 1 – resin inflow, 2 – folding and shearing; 3 – deformations caused by insufficient pressing of the material into the form [Sokołowski, 2016]

Different types of plastic foil are used to create an airtight bag when laying more complex shapes. However, this system is more complicated than using the vacuum table. Problems are caused by leakage from the bag, too much or too little foil used, separation from the element, or the displacement of prepreg layers.

## 2.5. Thermal cycles of carbon prepregs

After laying, the carbon prepreg should be properly hardened. The rising temperature accelerates the process of cross-linking. The hardening of composite materials is conducted in special ovens with heating/cooling speed control and precise temperature control. The material thermal cycles are selected based on the type of resin used in the prepreg and on the production technology being used. The material heating process is divided into initial hardening and final hardening. The elements should be properly prepared before being put into the oven. They should be hermetically sealed in a vacuum bag made of heat resistant foil. The diagram below shows an example vacuum package using a vacuum bag. This package can be modified depending on the materials used (Fig. 8).

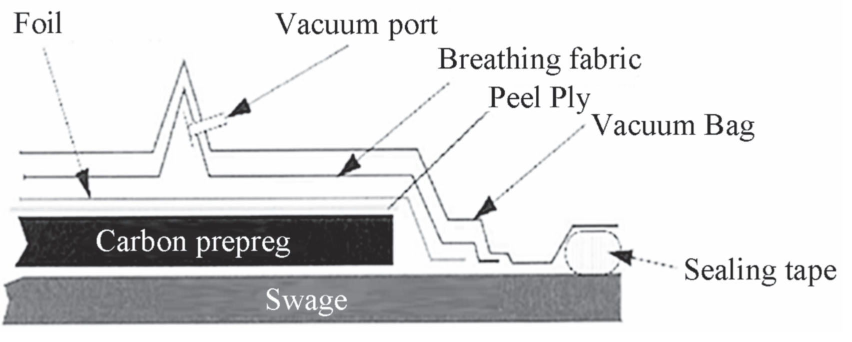


Fig. 8. Diagram of a vacuum package [Sokołowski, 2016]

The role of the layers shown in the diagram:

1. Swage – gives the final form to the produced element;
2. Sealing tape – seals the vacuum package;
3. Peel Ply – prevents the foil from adhering and gives the surface a coarse aspect after hardening;
4. Foil – prevents the breathing fabric from sticking to the prepreg;
5. Breathing fabric – transports the excess air contained in the prepreg;
6. Vacuum port – removes the excess air released by the prepreg

The polymerization cycle should be controlled at every insertion into the oven with the use of temperature sensors. The temperature sensors should be placed 50mm from the edge of the element. There should be at least two such sensors installed in order to monitor the temperature distribution in different areas of the element. These sensors should be placed where the material mass is the greatest and where it is the smallest (Fig. 9). Temperature measurement precision is very important and it should be accurate to within ±3°C. The output of each sensor should be registered for every hardening cycle.

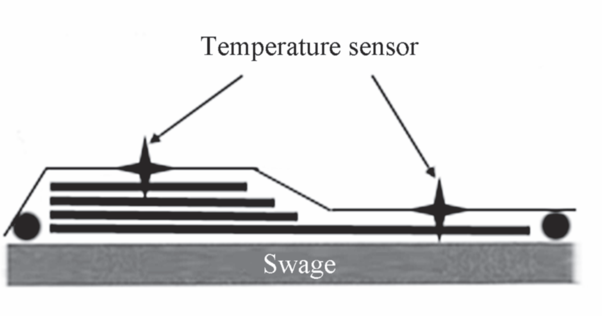


Fig. 9. Diagram showing the placement of temperature sensors [Sokołowski, 2016]

## 3. CONCLUSIONS

The critical parameters of the whole technological process of producing composite structures using carbon/epoxy prepregs are:

1. Temperature
   1.1. Storage: -18°C
   1.2. Cutting and laying: from +18 to +25°C
   1.3. Heating according to material specifications.
2. Humidity
   2.1. Cutting and laying: from 45 to 55%
3. The quality of the cut edges assures a better transport of resin and a better venting process. Fibers should not be shredded, displaced, bent.
4. Surface preparation – use of separation materials appropriate to the prepreg heating environment, which allows multiple stripping and the easy stripping of complex forms.
5. Heating process – temperature stability, heating/cooling speed.

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# PROCES PRZYGOTOWANIA I UKŁADANIA PREIMPREGNATÓW WĘGLOWYCH


**Streszczenie**

Praca zawiera informację na temat procesu technologicznego związanego z wytwarzaniem struktury kompozytowej z użyciem preimpregnatów węglowo-epoksydowych, z uwzględnieniem parametrów krytycznych procesu. Informacje opisane w publikacji przedstawiają kolejno:

1. Wykorzystanie elementów kompozytowych do budowy płatowca;
2. Sposób magazynowania i przechowywania preimpregnatów węglowych na osnowie z termoutwardzalnych żywic;
3. Charakterystyczne rodzaje splotów tkanin wykorzystywanych w preimpregnatach;
4. Sposób przygotowania materiału do procesu;
5. Narzędzia do cięcia;
6. Przygotowanie foremników;
7. Wykaz najpopularniejszych materiałów ich właściwości, plusy i minusy zastosowania;
8. Zagadnienia związane z rodzajami środków rozdzielczych;
9. Parametry doboru środków rozdzielczych w procesie wykonania struktur z preimpregnatów węglowych;
10. Proces układania warstw w strukturę warstwową;
11. Wady które powstają w wyniku niewłaściwego układania materiału w foremniku;
12. Przygotowanie struktury do wygrzewania oraz parametry techniczne samego procesu wygrzewania.


Słowa kluczowe: preimpregnat węglowy, element kompozytowy, środki rozdzielcze, foremniki.