COMBINED PREPREG AND INFUSION TECHNOLOGY -

INTEGRATED CFRP PRIMARY STRUCTURAL COMPONENTS

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OVERVIEW

The Combined Prepreg and Infusion (CPI) technology is a cost-efficient manufacturing method for the integral fabrication of complex structural components from carbon fiber composite materials. This technology is based on a combination of the prepreg and the injection technology both of which are already established in industrial production. Numerous experimental studies have been carried out to demonstrate the utility of this procedure for the manufacture of structural parts in aircraft construction.

1. INTRODUCTION

In order to reduce costs in the production of components from composite materials, the development of optimized fabrication procedures is of paramount significance. Just the handling and location of semi-finished fiber components accounts for approx. 30% of the cost of injection technologies and up to 45% of the cost of prepreg structures depending on their geometric complexity [1]. The substantial success of the prepreg technology in the aeronautics and aerospace industry is based on the excellent mechanical strength properties of the composite as compared to other manufacturing methods. The use of CNC tape-laying machines can clearly simplify the lay-up of prepreg materials for simple geometric structures. However, this is usually not feasible in the case of complex and integral components, such as stringers and frames. If mechanical stability and weight requirements necessitate the fabrication of such components by means of prepreg technology, the costs increase significantly.

The particular advantage of the LRI procedures is the provision of a comparatively free (compared to prepreg technology) combination of fiber and matrix materials which allows high flexibility in the fabrication process. Just as advantageous is the feasibility of the use of fabrics and Non-Crimp Fabrics (NCF). These two features effect a substantial reduction of the manual lay-up effort, while even the most complex geometries can be reproduced due to the excellent drapability of the materials. Unlike prepreg resins, injection resins require a lower viscosity in order to completely impregnate the dry fibrous material in the available process window. The lower viscosity comes at the price of increased brittleness of the resin matrix. Consequently, the mechanical strength values attainable in the components with the LRI procedure are, in some cases substantially, lower than the values attainable by prepreg technology.

2. COMBINED PREPREG AND INFUSION TECHNOLOGIES

A component manufactured by the Combined Prepreg and Infusion (CPI) technology consists of a preimpregnated area and an injected area, whereby the injection resin is supplied from outside through the sealing of the component [2]. Thus, the application of this manufacturing procedure allows elements of the structure with a simple geometry, but exposure to high stress to be assembled solely from prepreg materials. The reinforcement or force-transmitting elements with challenging geometries can be applied without much technical effort in the form of dry preforms for injection.

The subsequent autoclave-based CPI process includes the necessary injection of the dry fibers and joint hardening of the entire structure. The result of this procedure is a component that possesses not only the favorable mechanical properties of prepreg structures, but can also be manufactured much more cost-efficiently than a pure prepreg component because of the use of the injection technology.

2.1. Transition zone between prepreg and injection resin

For assessment of the fiber layers and distribution of the matrix systems in the sample material after completion of the CPI manufacturing process, it is customary to use polished specimen of a sample and analyze them under a microscope. The left side of Fig.1 shows a photomicrograph of a sample manufactured by the CPI technology. The fibers are all oriented in the same direction and cut transverse to the direction of the fibers. The upper part shows well-defined rovings manufactured by infusion technology. The individual prepreg layers can still be resolved in the lower part. It is not possible, though, to recognize the distribution of the matrix systems. The treatment of the injection resin with a fluorescent dye and the observation of the polished specimen by a fluorescent microscop reveal the distribution of the different resins (Fig 1, right). The prepreg resin shows up dark since it has no or little inherent fluorescence.

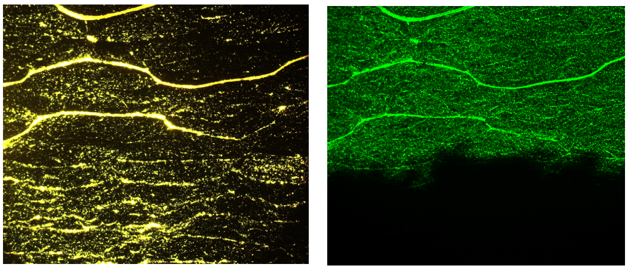

Fig.1: Photomicrograph of a hybrid sample under visible light (left) or ultraviolet light (right) in a fluorescence microscope [3]

This method can be used to analyze the effect of various selected process parameters on the spatial distribution of the matrix resins. The temperature and duration of the dwell time just before the resin injection emerge as the major process parameters in the CPI process.

2.2. Interlaminar shear strength

The successful introduction of the CPI technology will ultimately depend on whether the mechanical stabilities of the joined components are sufficient not to weaken the overall composite structure.

For this purpose, the investigation of the fracture toughness of the transition zone by peel tests is a very sensitive measuring procedure. This type of fracture-mechanical test is capable to reflect process parameter-related changes in the mechanical strength properties in the transition zone [4]. It can be concluded that the peel samples show that the resin transition zone is not a weak point in a component but may even tend to improve the properties of the transition zone.

The experiments described in the following were used to investigate the mechanical strength properties of the transition zone by means of the fracture toughness G_{IC}. It is shown that this type of fracture-mechanical test is capable of reflecting process parameter-related changes in the mechanical strength properties in the transition zone. Peel test samples were prepared and tested in accordance with DIN 6033. Since a crack in the form of an inserted halogen film was required for this type of sample, as shown in Fig. 2, it had to be ensured that this crack coincided with a relevant interlaminar separation plane containing the corresponding matrix transition. Since it was impossible to exactly determine the actual position of the prepreg resin in the transition zone, the number of samples for each parameter variant was increased to reflect four different crack levels.

A series of samples made from pure prepreg vs. pure injected fiber material was prepared in order to demonstrate the independence of the fracture toughness values thus measured from the crack level. The results obtained with this series of samples demonstrate the independence from the actual layer, since all samples yielded the sample fracture toughness values with a standard deviation of less than 2.5%.

Preliminary rheological tests on prepreg resin system 6376 were carried out in order to determine the sensible ranges of temperature and dwell time to be varied in the experiments. This resulted in the use of two dwell time temperatures and dwell time durations in the investigations of the influence of process parameters on the fracture toughness: 0.5 h at 90°C and 1.5 h at 120°C. The fracture toughness values of the samples with a dwel time of 30 minutes at 90°C are approx. 30% higher than those of the samples manufactured with a dwell time of 1.5 h at 120°C.

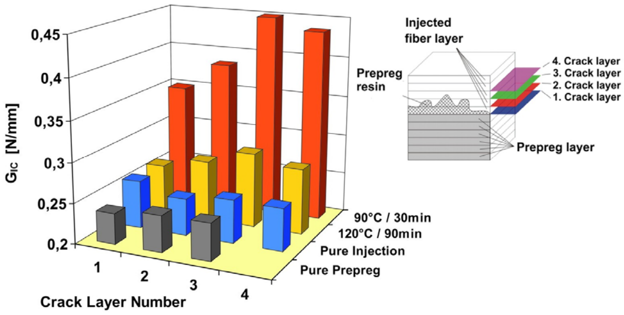

Fig. 2: Results from peel test dependent on the process parameters and the positions of the initial crack

The distribution of fracture toughness within the different layers of the hybrid-fabricated samples shown in Fig. 2 reveals a peak of fracture toughness at exactly the crack level at which the matrix transition zone is expected. The relatively low values in the direction of the prepreg at crack 1 were confirmed in tests on pure prepreg material. The fiber volume content determined in these tests by analysis of photomicrographs was approx. 61,5%.

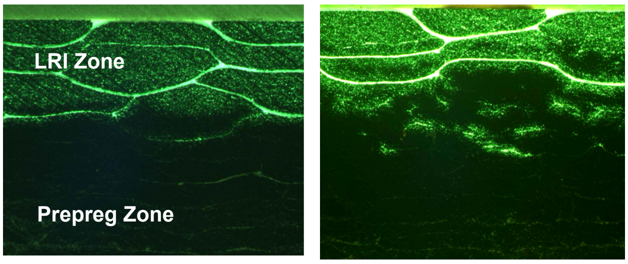

Fig. 3: CPI sample manufactured at a dwell time temperature of 120°C (left) and 90°C (right)

The influence of the process parameters on the local distribution of fracture toughness is shown in Fig. 3. In this test, both sets of process parameters show a nearly identical avage rising levels of the prepreg resin into the dry fiber material. Inspecting the matrix transition on the right side, colored resin areas completely surrounded by the prepreg resin system are notable. These "injection resin islands" are generated basicly by capillary forces within the rovings of the UD band. The areas surrounding the rovings remain rather dry and are subsequently filled with injection resin.

3. COMPONENT DEMONSTRATORS:

3.1. Stringer reinforced prepreg shell

So-called demonstrators are used not only to demonstrate the feasibility of manufacture and the testing of fabrication methods, but also to provide proof of the successful implementation of mechanical concepts.

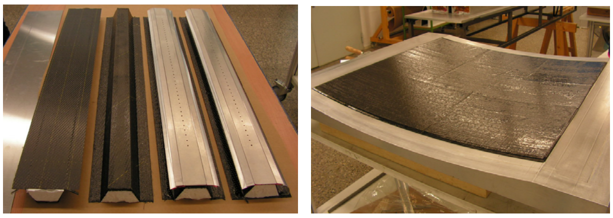

Fig. 4: Dry stringer preforms (left) and prepreg shell (right)

One possible and promising application of the CPI technology are prepreg shells with reinforcing elements made from dry and easily draped fibrous semi-finished parts. Such structures are always needed where thin-walled shells have to bear large torsional and flexural loads. Their membrane-like structure makes components of this type quite sensitive to buckling and therefore requires suitable reinforcement. Stringers and frames, e.g., are used for reinforcement in fuselage tubes and wing boxes. The stringers are provided in the form of so-called omega-stringers with a Rohacel foam core.

Several layers of woven fabric on top and one on the bottom were taped by means of a binding agent as a final layer in order to stabilize the stringer cells (Fig. 4, left). Stringers with this design are largely inherently stabile and do not require tools for their assembly other than covering plates for injection.

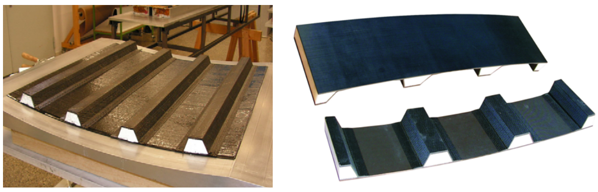

Fig. 5: Assembly of the stringers on the prepreg shell (left), finished stringer-reinforced prepreg shell made by the CPI technology (right)

The prepreg shell was built-up with the layers at angles of 0°/90° (Fig. 4, right). After lay-up of the prepreg, the stringers were positioned on the shell without any ifficulties in terms of tacking, then provided with covering plates, connected to the resin lines and sealed under a vacuum bag and evacuated. The finished shell demonstrators are shown in Fig. 5 (right).

3.2. Fracture Tests on spars

The CPI fabrication concept will be merely successful if not only the feasibility of the manufacture of components from the combined semi-finished parts can be shown, but also the preservation of the favorable properties of the materials in combination. For this purpose, a three-cell experimental spar was designed to allow a direct comparison in fracture tests. Two samples with equal geometry have been manufactured, a spar made solely by injection and a spar made with prepreg fractions [5].

The concept of the three-cell spar allows the load from the thrust of the web to be lead into the spar caps in multiple places rather than focussed in just one point of web-cap attachment compared to conventional I-beams. Tensile and compressive forces are taken up mainly by the cap bands in a spar.

High-stiffness and high- strength materials are preferably used as materials for the spar caps. These areas are particularly well-suited to accentuate the favourable properties of unidirectional (UD) carbon fiber prepregs. For this reason, an experimental spar each with injected and prepreg spar caps was constructed and then exposed to load until fracture occurred. The spar web cells are identical in the two spars and take the form of the preforms.

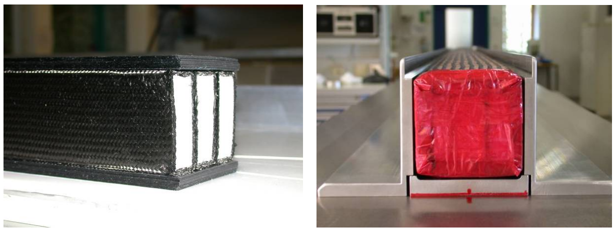

Fig. 6: Manufacture of the spar with prepreg cap belts (left); spar with final wrapping in the tool (right)

The structure of the spar with prepreg cap bands and web cells made of dry fabric tubes is shown in Fig. 6 (left). The right part of Fig. 6 shows the finished preform with its final layer of fabric tube in the tool (no lid yet) ready to be sealed and processed.The fracture experiments were very successful with regard to the nominal loads (15 kN): 15.27 kN were achieved with the pure wet spar and 16.24 kN with the CPI spar. In both spars, the pressure cap was shown to have failed due to pressure fracture.

However, unlike the wet cap, the prepreg cap remained attached to the web cells over the entire length of the component except for the fracture zone (Fig. 6, right). This results from the improved mechanical properties of the tough-modified prepreg resin that penetrated into the contact zone during the heating phase of spar production which is responsible for the better attachment of the spar cap to the web cells.

With regard to the ability of a functional component to bear mechanical loads, these observations and the fact that the calculated fracture loads were actually attained demonstrate the successful applicability of the CPI fabrication technique. The desired combination of the favorable properties of the semi-finished parts is indeed preserved in the finished component.

3.3. Large cut-out reinforcement

Another promising applications of the CPI technology are prepreg shells with large reinforced cut-outs like fuselage

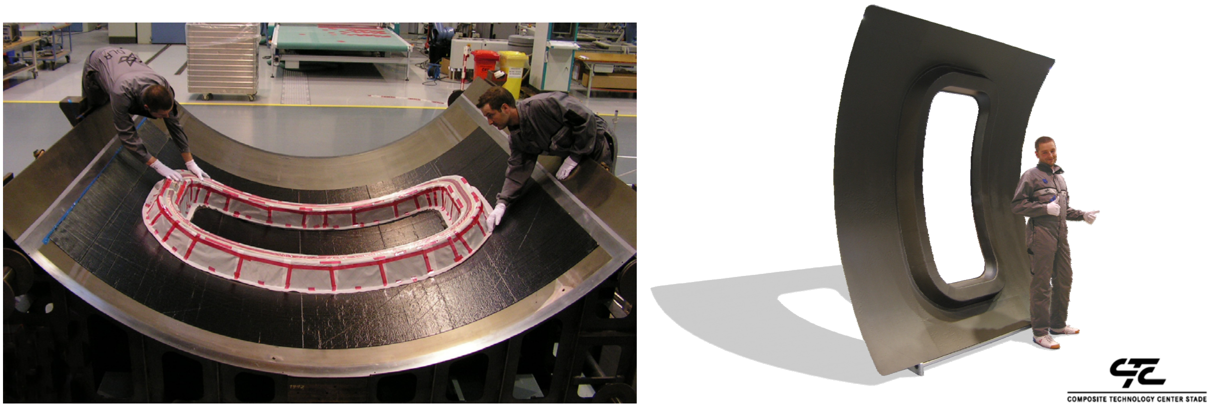

Fig.7: Assembly of the door surrounding structure on the prepreg shell (left), finished door cut-out with reinforcment made in CPI technology (right)

panels with passenger door or cargodoor cut-outs. The demonstrator presented was designed and built in cooperation with the CTC GmbH in Stade, Germany. Compared to actual designs for door surrounding structures, this design is quite simplified but demonstrates the main idea as a vantage start design. Similar to the stringer stiffened prepreg panel above, this module is built-up of a 3mm prepreg skin and a cut-out reinforcing foam core structure surrounding the edge of the cut-out. The foam core from Rohacell® 71 RIST HT is covered by several plies of manually draped woven fabrics. Both of them were precompacted to make up a preform part and then positioned on the prepreg shell (Fig. 4, left) ready to be sealed with a vacuum bagging. The infusion and co-curing process was arried out in an autoclave. The trimmed and cut out demonstrator prepared as an exhibit in the CTC is shown in Fig. 6, right.

4. CONCLUSIONS

The Combined Prepreg and Infusion (CPI) technology is an attractive alternative to established manufacturing methods. The suitability of this novel method for the manufacture of aeronautical components has been demonstrated by a large variety of methods. For this purpose, components and samples manufactured with this technology were systematically tested for their performance. The investigations focussed on the compatibility of the matrix materials, characterization of the transition zone, determination of the mechanical properties, as well as the manufacture and testing of entire assemblies. The latter tests were designed to reveal the behavior of the material when exposed to complex loads and serve as the basis of a comparison to composite materials manufactured by other technologies.

It can be concluded that the fabrication procedure investigated in this work is, on principle, suitable for the manufacture of carbon fiber-reinforced composite materials. Negative effects on the properties of the components due to the combination of two different matrix materials and different types of semi-finished components were not detected. In fact, there are even some synergistic effects resulting from the combination of fabrication methods in that the fracture toughness of the resin transition zone was found to have improved.

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