Application of Lightning Strike Protection on Thermoplastic Structures by Automated Fiber Placement

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Abstract:

Similar to thermoset composite parts, for carbon fibre reinforced thermoplastic parts a layer to protect the airplane structure from lightning strikes has to be applied on the outer surface. The automated integration of this lightning strike protection (LSP) material onto highly double curved surfaces like the rear end, using existing technology like Automated Fiber Placement (AFP), had been analysed. Beside the development of a hybrid LSP material, which fulfils the requirements of an AFP process, automated layup trials with Xenon flash lamp heating had been realised to determine capable process parameters. Furthermore, test specimens with AFP specific cross layup design and different material combinations had been manufactured and the quality of the LSP layer had been investigated. The fundamental trials demonstrate the feasibility of the integration of a thermoplastic LSP layer using AFP.

Keywords: Lightning Strike Protection, Automated Fiber Placement, Expanded Copper Foil, Perforated Copper Foil, Thermoplastic, Xenon Flash Lamp

Introduction

Lightning strikes can cause huge damage to aircraft structures, if they are not protected by an outer surface with high conductivity. For this reason, similar to thermoset composite parts, a lightning strike protection layer (LSP) also has to be applied to the outer surface of carbon fibre reinforced thermoplastic parts (CFRTP). The automated integration of this material, especially on highly double curved surfaces like an aircraft rear end is the focus of this paper. Automated Fiber Placement technology (AFP) [1], where several tows can be laid up simultaneously on a surface, seems to be an appropriate technology for this application. Because of the narrow tow width of 6.35 mm, steering of the material may be realized for double curved surfaces and a parallel layup of courses can be achieved. Beside these advantages, high process reliability and reduced investment costs because of existing production equipment are other benefits.

This paper addresses the automated fibre placement of thermoplastic LSP material under consideration of process related manufacturing constraints. Following objectives are focussed:

- Manufacturing of thermoplastic LSP material
- AFP layup trials and processibility
- Conductivity between two LSP layers of an AFP specific cross layup design

State of the Art

In serial production of carbon fibre reinforced plastic (CFRP) aircraft parts, the LSP layers, which typically consist out of an expanded (ECF) or perforated copper foil (PCF) surrounded by a resin layer, are mostly applied manually by skilled workers [2]. In case of the A350 wing, Airbus uses Automated Tape Laying (ATL) technology to deposit one wide tape material onto the surface automatically [3]. To ensure a sufficient conductivity between the wide tapes, usually an overlap in between is preferred. A method for automated application of thermoplastic LSP onto a CFRTP structure is described in [2]. In the Arches Box TP project, STELIA Aerospace demonstrated the automated layup of the material onto a CFRTP structure with AFP [4]. Plain copper tape without any perforation had been used as LSP material. However, further literature dealing with automated application of this material could not be found. One reason for this might be the lack of available material on the market until now. This leads to a lack of detailed information of the layup process like material configurations, process parameters, layup design or electrical properties.

Nevertheless, the fundamental layup process of thermoplastic LSP mostly seems to be similar to the layup process of thermoplastic carbon fibre prepreg (TP-Prepreg), especially regarding the high temperature, which is needed to melt the thermoplastic matrix. To achieve this, heating technologies like hot gas torch, infrared or laser had been mainly used [5-7]. A relatively new technology is the Xenon flash lamp by Heraeus [8]. Especially in comparison to laser heating, it offers the potential to process thermoplastics in a comparable speed, but with considerably lower safety efforts, which leads to lower investments. Promising AFP layup trials had been realised by Haase et al. at the German Aerospace Center in Stade, Germany [9]. For this reason this technology also had been used for processing thermoplastic LSP here (Fig. 1).

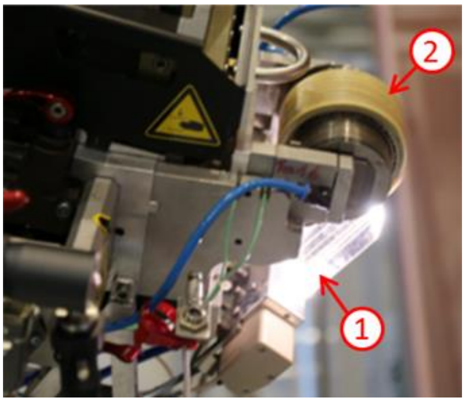

***Fig. 1:** AFP end effector with Xenon flash lamp (1) and compaction roller (2)*

Experimental Trials

As mentioned before there is a lack of available thermoplastic LSP on the market. For that reason some fundamental trials to manufacture hybrid material, which fulfils the requirements to an AFP process, had been performed in a first step. Hybrid material in this case means a combination of a high conductive layer with additional layers to address AFP process requirements. In a first step the raw materials had been stacked by hand and consolidated in an autoclave afterwards. In a second step the tapes had been cut to 6.35 mm width after consolidation. Two types of lighting strike layers, ECF and PCF had been tested. Various stacking of raw materials had been manufactured focussing the AFP processibility of the material (Fig. 2). Following raw materials had been used:

- Thermoplastic film (TP): 0.06 mm thickness
- Expanded Copper Foil: 195 gsm
- Perforated Copper Foil: 115 gsm
- TP-Prepreg: 195 gsm / 0.184 mm thickness

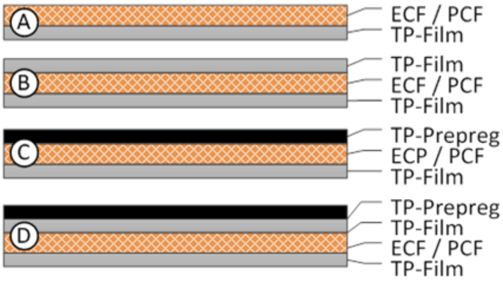

***Fig. 2:** Hybrid-LSP material with different stacking*

With focus on AFP process reliability e.g. tape feeding and cutting, the automated layup of the hybrid LSP material had been investigated in the following step. Furthermore, these trials should prove that the described material can be processed with standard AFP technology without major modification. Layup on a female mould surface as first ply as well as on a male mould surface as last ply of the structure had been investigated. To achieve the high temperature, which is needed, the end effector had been equipped with a 6 kW/55 mm wide Xenon flash lamp (Fig. 1).

With AFP, the narrow tows can be laid up with steering without any damage of the material. For double curved surfaces, this capability allows a parallel layup, and therefore constant gaps or overlaps between the tows can be achieved, depending on the specific needs of lighting strike protection. Especially for laying up LSP on double curved surfaces, this is important in order to achieve a homogenous surface and therefore a homogenous conductivity. Furthermore, using narrow tows with AFP instead of wide tapes allows a re-thinking of LSP layup designs. Possible concepts like cross layup, longitudinal overlap or mitre joint had been described by Haase et al. in [9] (Fig. 3). It is expected that the layup design of the LSP layer has major influence on the lightning strike properties. Taking the conductivity into account it is assumed that the mitre joint has, due to the poor contact of the tows to each other, the lowest conductivity compared to cross layup and longitudinal overlap. On the other hand, to realise overlaps in a longitudinal overlap design, a modification of the fibre guidance of the multi-tow end effector is necessary. For mitre joint and cross layup no modification is needed and the tows could be processed in their standard way. Because of these reasons, in a first step this paper is focussing the cross layup design with two striped plies laid up perpendicular to each other.

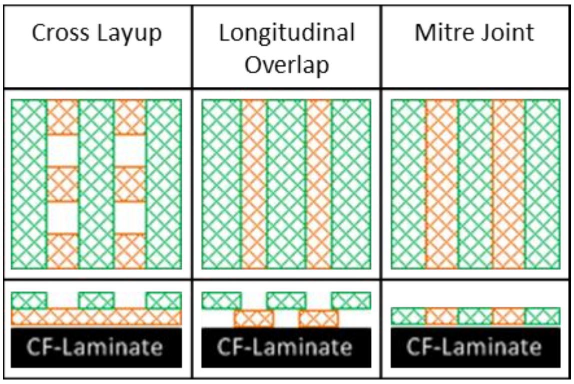

***Fig. 3:** Possible layup designs for AFP*

CFRTP laminates with 2 mm thickness and LSP surface with material type B in Fig. 2 (with ECF and PCF) had been manufactured and compared to each other regarding conductivity of the LSP plies. For this, the electrical resistance at the overlap had been manually measured with 4-point probe method (Fig. 4). To determine the increase of electrical resistance due to overlap, the electrical resistances between the points AB, BC, CD and DA can be measured and compared with those between AC and BD.

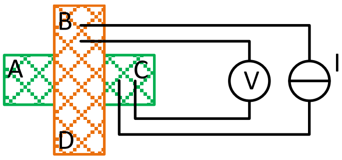

Fig. 4: *Measurement of electrical resistance at the LSP overlap*

Furthermore it can be expected that the better the contact between the two plies, the better is the conductivity of the surface. For this, micrographs of the cross section had been determined to measure the distance of the two overlapping copper layers to each other.

Results and discussion

All manufactured hybrid-LSP types show good quality in regards of homogeneity and void content. In all cases the copper layers are fully embedded in between the thermoplastic film, which on the other hand means that one layer of thermoplastic film is enough and two layers are not needed (Type A and C in Fig. 2). Layup trials with material type A show some problems regarding processing with the end effector. On the one hand the bending stiffness of the material is too low so it mostly gets stuck in the end effector when being fed. On the other hand, if ECF is used, the material stretches during the layup (Fig. 5) and the width of the material decreases. The reason for that is because the thermoplastic resin melts right before the material gets consolidated to the surface to bond with the substrate. At this moment the ECF has to absorb the entire occurring tow tension of 2-3 N per tow which results in a stretched ECF layer. Because of this expected behaviour, type C in Fig. 2 had been manufactured to create a more stable material (Fig. 6).

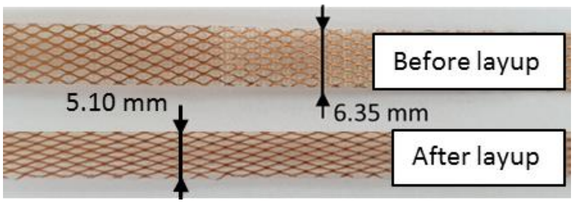

Fig. 5: *Stretching of material during layup*

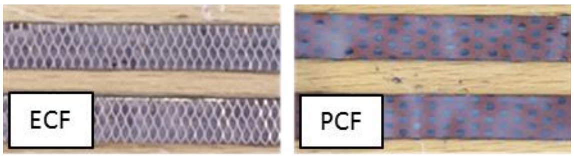

Fig. 6: *Reinforced ¼“ LSP tows*

With the additional reinforcement layer of TP-prepreg the bending stiffness increases and due to the UD-fibres stretching can be avoided. With this modification the problems could be solved and the material can be processed within the end effector, including cutting with the punching technique. For both layup concepts, as first ply on the mould surface and as last ply on the composite laminate (Fig. 7), layup trials with the material had been successful. To achieve high bond strength between the first ply and the layup tool a thermoplastic film is applied to the layup mould surface. Vacuum is applied to the entrapped volume between the thermoplastic layer and the mould. If the LSP is laid up afterwards, the thermoplastic layer melts locally at the compaction point and consolidates with the laid up material. Because this method leads to an increase of structural weight, layup as last ply should be favoured. With the available 6 kW/55 mm Xenon flash lamp the desired temperature of 380°C could be achieved at a layup speed of 2400 mm/min.

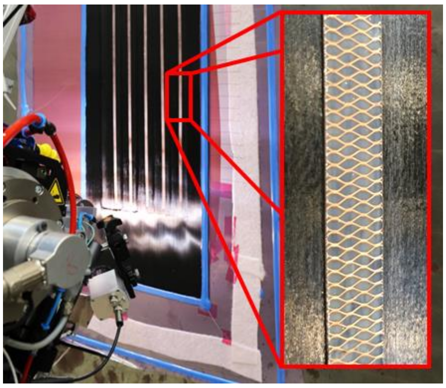

Fig. 7: *Automated layup of single thermoplastic ¼” LSP tows onto thermoplastic material*

The CFRTP laminates (Fig. 8) with cross layup design show smooth surfaces for ECF as well as for PCF. No waviness of the surface due to higher thickness at the overlaps could be determined.

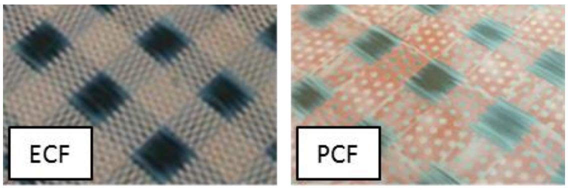

Fig. 8: *Laminates with cross layup design for LSP*

It was expected in advanced that the thickness of the separating thermoplastic layer between the two LSP plies would be higher for PCF than for ECF. The larger surface compared to ECF could lead to more trapped resin between the plies. The result would be a higher increase of electrical resistance due to the overlap. However, measurements show that for PCF and ECF, the overlap increases the electrical resistance by the same amount of about 6 mΩ (Table 1). Although this means a doubling of the resistance for ECF and tripling of resistance for PCF, the values are still of the same order of magnitude compared to the resistance without overlap. This result shows that no clear differences between the two LSP types could be identified with regard to the conductivity of the overlaps and that the cross layup design can be used for both LSP types. Micrographs of the cross section confirm this observation (Fig. 9). For both LSP types the separating thermoplastic layer is almost identical at 11 µm for PCF and 13 µm for ECF.

Table 1: *Electrical resistance at the overlaps*

	No Overlap	Overlap
ECF	5,8 mΩ	11,2 mΩ
PCF	3,3 mΩ	9,9 mΩ

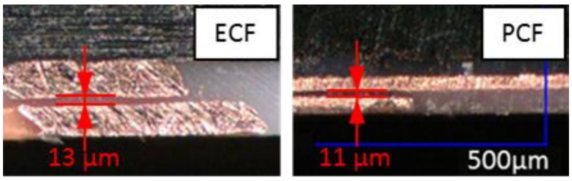

Fig. 9: *Cross section micrographs of the overlaps*

Summary and Outlook

For application of thermoplastic LSP material onto double curved CFRTP structures, the automated integration of this material with AFP technology and Xenon flash lamp had been investigated. Hybrid materials consisting out of PCF or ECF had been manufactured with different stacking and subsequently tested regarding processibility with AFP. Results show, that plain LSP with thermoplastic film could not be processed due to low bending stiffness of the material. Adding a reinforcement layer in layup direction like UD-prepreg increases the bending stiffness, which leads to a successful processing of the material. No major modification of the end effector, for example for cutting or feeding of the material, was needed. Furthermore the cross layup design had been investigated regarding conductivity. Results show that the increase of electrical resistance due to the overlap is about the same value for PCF and for ECF and therefore the cross layup design could be used for both LSP types.

The results presented here demonstrate a successful integration of LSP layers onto thermoplastic laminates in 2D. Nevertheless, they only give a short overview of the layup process and its material specific aspects, which have to be considered. To get a more detailed understanding of the layup process for 3D parts or the suitability of the layup design to protect the airplane from lightning strike, further investigations have to be realised. Therefore in a following step lightning strike test will be realised to evaluate the layup design. Furthermore, the layup process will be investigated regarding steering capability of the material for a layup onto a double curved surface. It is expected that due to the different structure of ECF and PCF a different behaviour regarding limit values will result.

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Disclaimer

The results, opinions, conclusions, etc. presented in this work are those of the authors only and do not necessarily represent the position of the JU; the JU is not responsible for any use made of the information contained herein.

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