IN-SITU CONSOLIDATION OF POLYAMIDE (PA) COMPOSITES BY AUTOMATED PLACEMENT TECHNOLOGY

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Keywords: thermoplastics, in-situ consolidation, polyamide, peeling tests

Abstract

FIDAMC (Foundation for Investment, Developing and Application of Composite Materials) has developed a thermoplastic fiber placement technology based on laser beam heating that will enable consolidation of thermoplastic material out of autoclave.

FIDAMC is participating in the topic FoF-02-2014 (HORIZON 2020): Research on efficient integrated systems for the Manufacturing of complex parts based on unidirectional tapes for the automotive and aeronautical Industry (FORTAPE) and has adapted the laser in-situ consolidation process for the use of fire –proof polyamides for its application in secondary structures interior cabin parts.

Polyamides are selected due to their optimum balance in terms of material costs and mechanical performances compared to other possibilities [2]. This polymer has been previously used in consolidation processes but not in a laser in-situ technology. The material under study has been supplied by Canoe with different types of reinforcements and different chemical formulation.

Research works are focused on adapting this new type of material to the In-situ consolidation process. In this line, processing parameters will be fixed to develop a laser-assisted thermoplastic tape placement process for unidirectional carbon fiber reinforced Polyamide (CF/PA) tapes. Peel samples have been built and tested in order to define the quality of consolidation laser adjustment [3].

Excerpt from ISBN 978-3-00-053387-7

1. Introduction

1.1 State of the Art

The use of thermoplastic matrix in carbon fibre reinforced components has been growing continuously in automotive and aerospace applications. These composites are becoming the material of choice for replacing traditional metallic materials because higher strength to weight ratios, better chemical and impact resistance and design flexibility

Besides thermoplastics have recognized aspects such as excellent FST (Fire, Smoke, and Toxicity) properties, higher mechanical properties and damage tolerance, chemical resistance, infinite shop life, weld ability of thermoplastic components, reuse of material and shorter manufacturing cycles compared to their competitor thermosets. Thermoplastic resins offer a high potential not only regarding material properties, but also in order to reduce processing, logistic, operation and life cycle costs.

Current thermoplastic composite parts are predominately processed with methods including stamp molding, thermoforming, autoclave molding, diaphragm forming, roll forming, filament winding and pultrusion and joining technologies such as electrical resistance, ultrasonic and induction welding.

Besides thermoplastic prepregs such as PEEK, PEKK or PPS more than known in applications with laser-powered tape placement machines a variety of materials as Polyamides (PA) is a growing market due to material costs [2]. This polymer has been previously used in consolidation by stamp forming [5] and other example of Polyamide in consolidation in lamination machine with diode laser was the Fiberchain project using Glass Fiber and PA66, PA6 and PA12 [6].

1.2. Automated in-situ lay up and consolidation.

The opportunity for thermoplastics is to approach to the automation of the lamination process with technologies such as a gas torch, infrared or laser as heating sources added in automated tape placement.

In-situ consolidation processes currently are the main goal of most research and technology projects on thermoplastic materials. The aim of these processes is to avoid the use of autoclave and to reduce the number of processing steps, and consequently reduce the cost considerably, while maintaining competitive properties.

FIDAMC (Foundation for Investment, Developing and Application of Composite Materials) has developed a thermoplastic fiber placement technology based on laser beam heating that will enable consolidation of thermoplastic material out of autoclave, starting to use this process for primary structure applications with diode laser as a heating source and PEEK as the base thermoplastic polymer [1].

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FIDAMC has been extensively researched, developed and validated this technology through the life of different Clean SKY (ISINTHER, JTI_CS-2011-1-ECO-01-021, GRA (Green Regional Aircraft) 2014 and OUTCOME JTI-CS2_2014-CPW01-AIR-02-02) and Spanish National projects as TARGET-CENIT Program 2010 [1].

Fig. 1 shows the evolution of this technology in Fidamc.

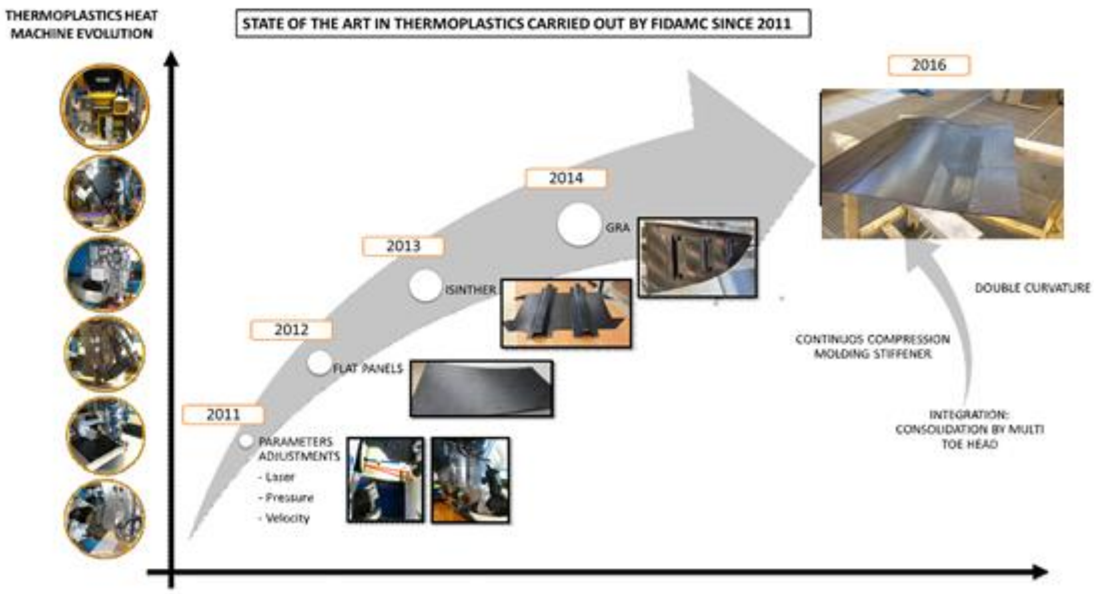

Figure 1 Evolution of thermoplastic head machine from 2011 and the achievements in technology and structures in FIDAMC.

1.3. Machine description and process parameters.

Machine showing in Fig. 2 consists in an automatic head that incorporates a system to melt, deposit and freeze the thermoplastic unidirectional tapes, ply by ply on a mandrel tool. The process requires a continuous heating source by laser type Diode, because its high energy, controllability and high efficiency. An infrared camera is incorporated to the head to measure the temperature at the focal spot in the NIP (contact with roller) and length in the substrate and adjust the power and the angle of the laser optics. Other components of the machine head include an on-line consolidation roller. Both incoming tape and substrate are consolidated by the action of the consolidation roller under controlled heat and pressure.

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Figure 2 Automatic lamination machine

The variables to be controlled and improved during the process to achieve enough consolidation were the lamination speed, temperature and thermal history and pressure. Laser profiles and velocity of the system establish the thermal history of the material. The velocity is direct related with the exposure time of the material to temperature, and with the heat transfer through the whole laminate [1].

2. Project objetives.

Novel in-situ consolidation technology is developed to manufacture complex composite parts without the necessity of autoclave for secondary structure assemblied in interior cabin complying with fire proof regulations, using a combination of carbon fiber and a new Polyamide (PA11) supplied by CANOE/ARKEMA. Our study is focused to adapt the chosen material to the existing Automated Fiber Placement machine assisted by Laser in FIDAMC and in particular the customization of laser configuration including (See Fig. 3):

1. Selection of preferred material among four different types of unidirectional a carbon fiber reinforced tapes from Canoe supplier.
2. Validation of process parameters starting with thermal history.
3. Optain the optimum laser profiles with the aid of peeling samples from laser assisted lamination machine for the four materials.
4. Finally, Demostration prototype of aeronautical window frame to validate the combination of new material and machine approach.

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3. Results and discussion.

The followed methodology in this study is shown in the Fig. 3.

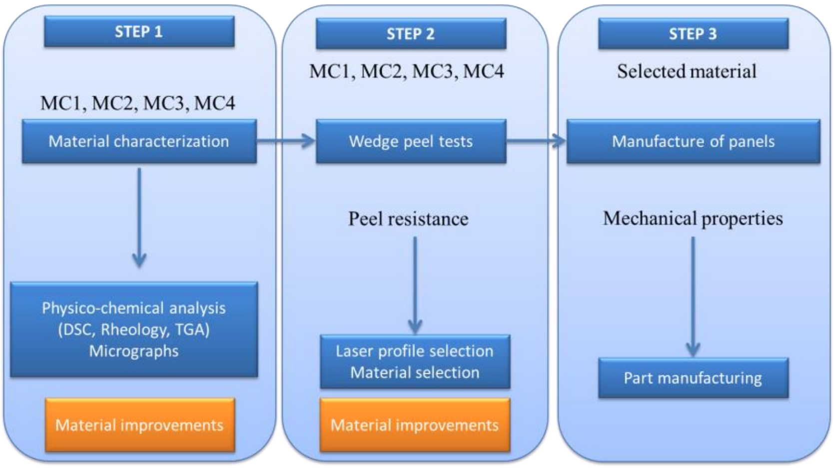

Figure 3 Methodology graph.

The preliminary process parameters have been obtained with standard laboratory tests as DSC (Differential Scanning Calorimetry) and Rheology. Results of the material characterization is summarizing in the Table 1 with the physical-chemical parameters.

Table 1 Material data

	M1: PA11A/T700S	M2: PA11A/AS4	M3: PA11B/AS4*	M4: PA11/AS4
PAW (g/km)	1400	1360	1410	1230
FAW (g/km)	800	858	858	800
%Vol. Fibre	43	50	47	53
%Vol. Matrix	57	50	53	47
Thickness (µm)	230±10	198	185	185±10
Matrix density (g/cm^3)	1.03	1.03	1.03	1.03
Fibre density (g/cm^3)	1.8	1.79	1.79	1.8
T_g (ºC)	43-45	48	48	43-45
T melting (ºC)	181-182	189.5	188.3	181-182
Melting Enthalpy (J/g)	-48.6	-46.64	-54.4	-29.5
Crystallinity (%)	21.5	20.6	24	13

Next step was the assessment of the goodness of consolidation with different laser adjustmen in existing thermoplastic automated lamination with the aid of peel specimens. The laser profile is optimized taken into account the heat distribution, feeding tape and laser power control. Peeling samples of two plies of unidirectional (UD) cabon fiber and PA11 were built under various processing conditions such as laser power, lamination speed and maintaining the roller pressure at 50 kg in order to determine its processability and temperature profile. Experimental plan and laser profile of one trial is included below, Figure 4. Dimensions of the peeling samples are170mmx 25mm with $(0º)_{2T}$, they have a consolidated length of 100 mm and 70 mm of kapton creating a debonding area as precrack. The tool in the testing machine is a wedge to act separating both sides of specimen in its interface and the load versus displacement is registered along the test and the load value divided by the width of the sample gives peeling apparent resistance. Photo of testing tool and images of samples before and after testing are shown below, see Fig. 5.

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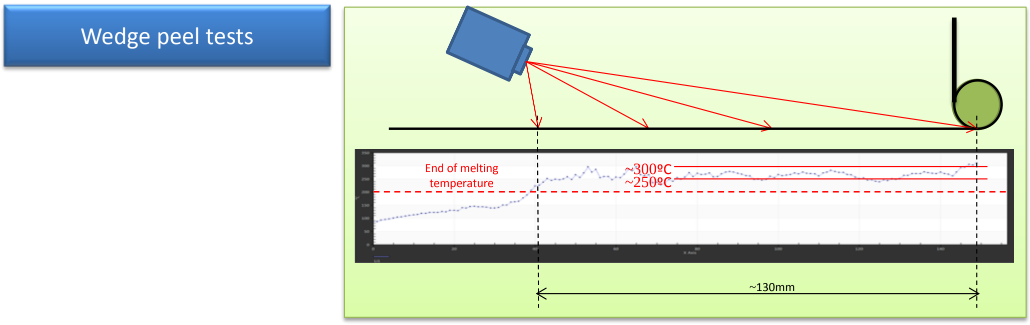

Test	Lamination conditions	Compaction pressure (kg)	Tooling temperature (°C)	Lamination velocity (m/min)
Test 1	M1: 200-250°C M2: 225-275°C M3: 225-275°C M4	50	Tamb	2
Test 2	M1: 350-400°C M2: 325-375°C M3: 225-275°C M4	50	Tamb	2
Test 3	M1: 300-350°C M2: 250-300°C M3: 250-300°C M4: 225-270°C	50	Tamb	1

Figure 4 Experimental plan and laser profile with the thermal history of sample during processing monitored by thermographic camers.

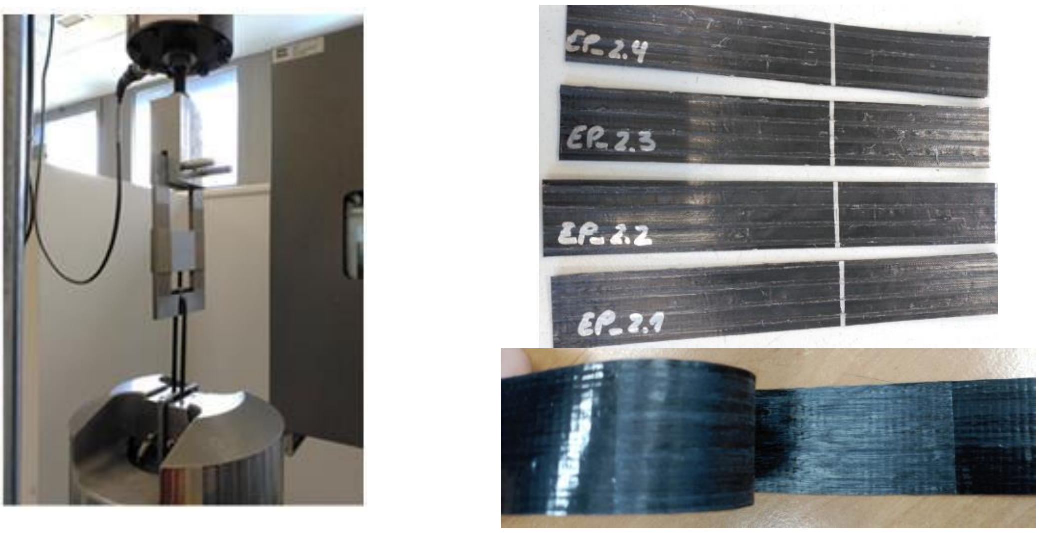

Figure 5 Samples at 2 m/min and laser power of 240W before and after testing

Fig. 6 summarises the results of the preferred material M2 with PA11 and AS4(Hexcel) tape without sizing. A peel force value between 3-3.5 N/mm were obtained and the chosen profile and power laser let achieving thermal history during processing between 250-300ºC (Tmelting=190ºC).

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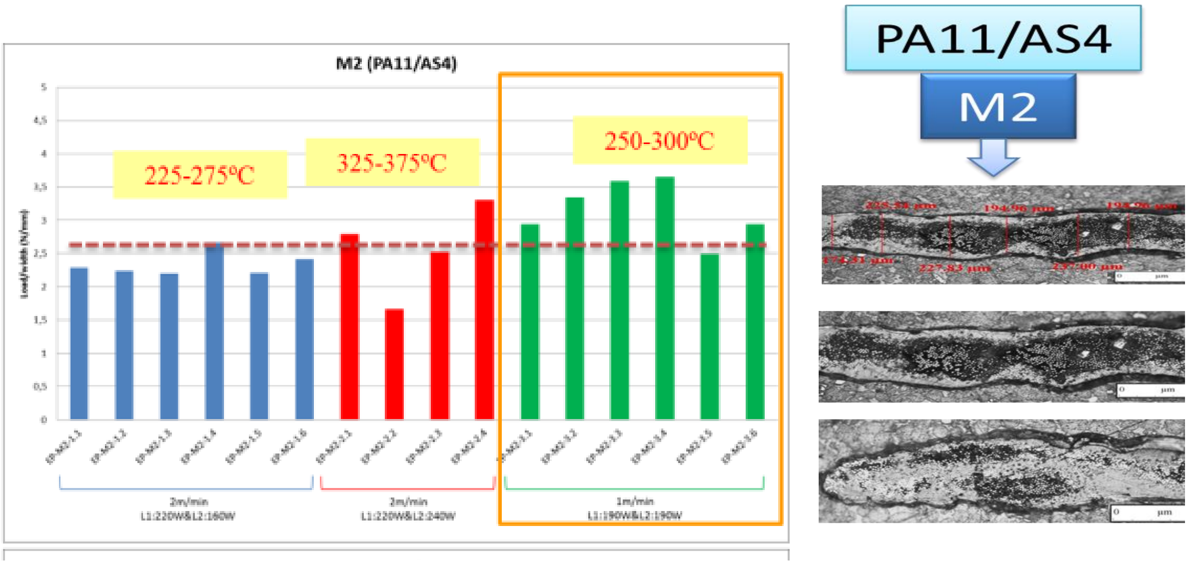

Figure 6 Peel force results and raw material micrographs (material M2).

Finally, flat panels are manufacturing with this preferred material and the working parameters obtained in previous phase and will be checked In-plane shear strength (IPSS) property in next months. Fig. 7 shows the first built panel and monitoring thermal history durig the lamination.

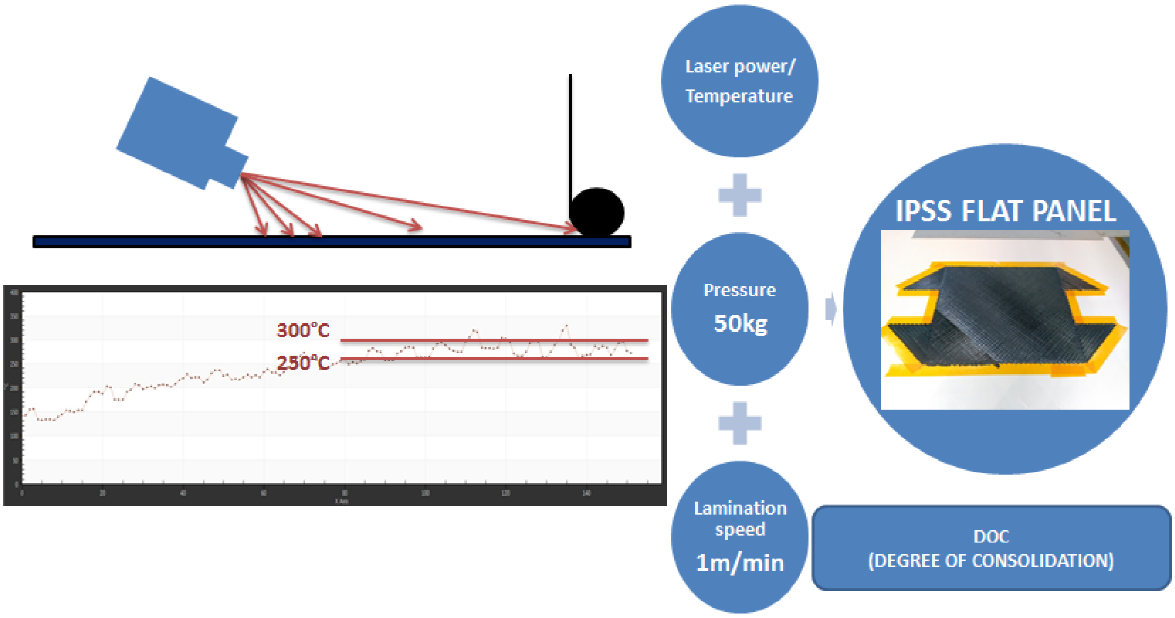

Figure 7 IPSS flat panel.

Acknowledgments

The authors would like to thank the European Comision for the finantial support and our colleagues of Fortape Consortium.

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3. Conclusions

Based on these results, the working parameters, speed, pressure and temperature, have been fixed and flat panel (quasi-isotropic 16 plies) has been built.
Peeling specimens at different lamination speeds and temperatures were used to qualify the interlaminar bond strength. The resulting peel forces reach a range 3-4 N/mm which are in line with values reported in the literature for specimens manufactured by laser assisted automated tape placement: 3N/mm for CF/PEEK [3, 4, 7] and 1.5-1.7 N/mm for carbon fiber with PA6 and PA66 [3].

It may therefore be concluded that with the material supplied by Canoe/Arkema (CF/PA11) it is possible the lamination and consolidation in Automated Fiber Placement with laser as heat source.

The unidirectional tapes under this investigation show an unhomogeneous fiber/matrix distribution and high level of voids (Fig. 6), that it may improve in order to increase the process efficiency of lamination/consolidation speed and demonstrate that the thermoplastic tape placement is economically competitive with the thermosets lamination and avoiding the autoclave participation in the case of thermoplastic.

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