OUT-OF-AUTOCLAVE MANUFACTURING OF LARGE INTEGRATED STRUCTURES USING THERMOPLASTIC COMPOSITE MATERIALS

J. Dolan[1], A. Doyle[1], C. M. Ó Brádaigh[2], D. Jaredson[3]

[1] ÉireComposites Teo., An Choill Rua, Indreabhán, Co. Galway, Ireland
[2] Mechanical and Biomedical Engineering, National University of Ireland, Galway, Ireland
[3] European Space Agency, ESA/ESTEC, Keplerlaan 1, 2201AZ Noordwijk, The Netherlands

Abstract
This paper describes the design and manufacture of an integrally-stiffened curved panel for space launcher applications, using advanced thermoplastic composite materials. This stiffened panel is based on the design of the 2/3 interstage of the Ariane 4 space launcher. The panel is a 1/8th section of the original structure with approximate dimensions of 2m x 1m, consisting of a curved base panel and T-section stiffeners. The base and the stiffeners are manufactured using novel out-of-autoclave processing and assembly techniques. Electrically-heated tooling technology enables the consolidation of the base skin and the thermoforming of the stiffeners using vacuum pressure alone. To provide the necessary heating, the proprietary mould tooling employs a metal tool with ceramic/glass-fibre panels with embedded electrical heating elements. The parts are assembled using an amorphous interlayer bonding process which takes advantage of the ability to fusion-bond thermoplastics quickly and without the use of adhesive or fasteners. Test panels verified the design and demonstrated the buckling capability of the structure. A full-sized manufacturing demonstrator was assembled.

1.0 Introduction

Out-Of-Autoclave (OOA) manufacturing has gained much attention in the world of space and aerospace structures in recent years. The increasing size and complexity of thermoplastic composite components being manufactured has provided challenges to conventional methods of production. Autoclaves and large presses (over 2 metres length capacity) require large capital expenditure. Alternatives with lower initial costs and faster cycle times are being increasingly sought [1].

OOA consolidation provides many advantages over traditional manufacturing methods; relatively short cycle times, efficient heating and cooling and low initial capital expenditure. The potential of OOA manufacturing has been proven for thermosets and temperatures up to 200°C [2]. This project looks to extend the use of the technology for consolidation of larger structures at temperatures up to 400°C and develop the use of OOA joining for assembly.

To demonstrate these advantages, a section of the European Space Agency space launcher Ariane 4 was selected for re-design and manufacture.

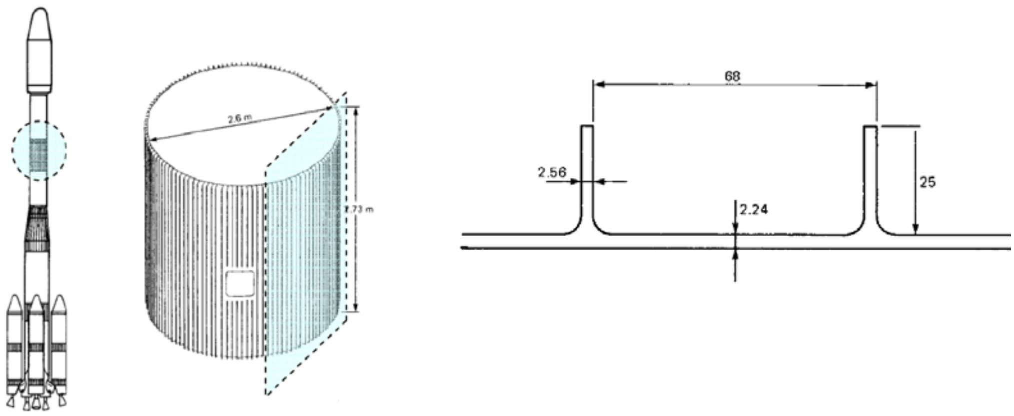

Figure 1: Detail view of original Ariane 4 2/3 interstage

The structure was originally manufactured from aluminium alloy and subsequently re-designed using thermoset composites [3]. It is composed of eight curved sections, bolted together to form a 2.6 metre diameter cylindrical structure. The integral stiffeners form a blade-stiffened structure with a blade height of 25mm.

The panel was re-designed so as to manufacture the curved base panel and the stiffeners separately using vacuum only OOA consolidation. The stiffeners are designed as L-section stringers and bonded back-to-back onto the base to form inverted T-section stiffeners on the structure.

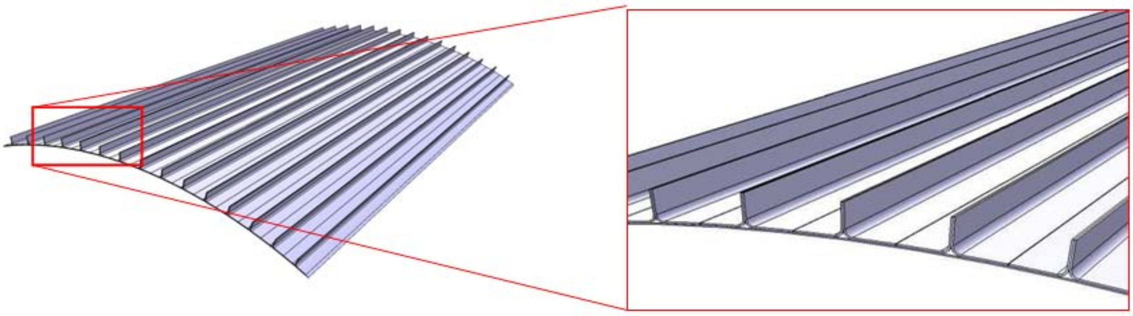

Figure 2: Re-designed configuration; base panel with bonded T-section stiffeners

2.0 Process Development

2.1 MECH Tooling & OOA Processing

A schematic of a MECH^{TM} (Mould Efficient Cooling and Heating) Tool and a typical process cycle is shown in Figure 3. The metallic tool surface has an attached ceramic plate with embedded electrical heating elements. The tool is connected to a three-phase electrical supply and provides very efficient heating of the part. The tool is vacuum bagged and attached to a vacuum pump which applies 1 bar pressure during consolidation. With heat being applied directly to the tool surface, very rapid cooling can take place when the cure is finished, with the component remaining under vacuum. The entire cycle time for thermoplastic components can last just 20-30 minutes from lay-up to demould and this has not yet been optimised for speed.

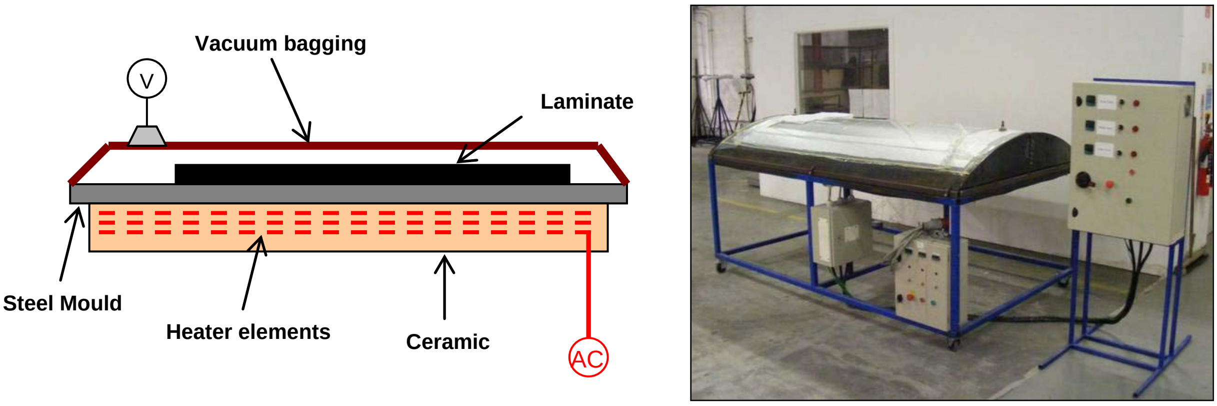

Figure 3: Schematic of MECH^{TM} Tool and demonstrator tooling

2.2 Base Manufacture

A large curved MECH^{TM} Tool was manufactured and is shown in Figure 3. The tool surface is used for both the consolidation of the base and for positioning the stiffeners during assembly. The heating system was designed to allow maximum control of the heat distribution to minimise possible heat losses due to the size of the tool.

Trial laminates were manufactured from CF-PEEK (supplied by Cytec) with the tool running to a maximum temperature of 400°C. Very high quality laminates were produced with low porosity levels and typical void content of less than 1%. A typical CF-PEEK laminate is shown in Figure 4 along with a micro-section through the thickness.

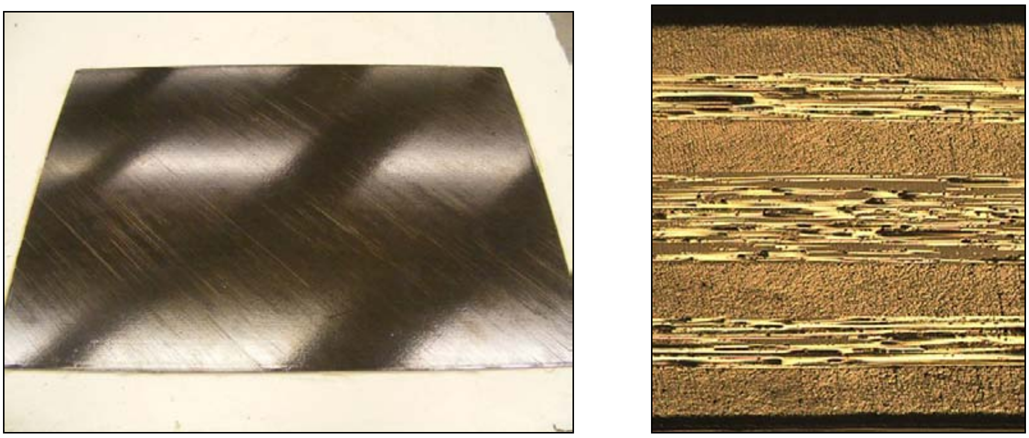

Figure 4: OOA CF/PEEK laminate and micrograph (x30 mag)

2.3 Stiffener Forming

The manufacture of 2 metre long stiffeners was performed using a novel forming technique in which the blank for forming was positioned on a MECH^{TM} Tool, vacuum bagged, partially melted and a vacuum pulled to create the required geometry. A schematic of the stiffener forming process is shown in Figure 5.

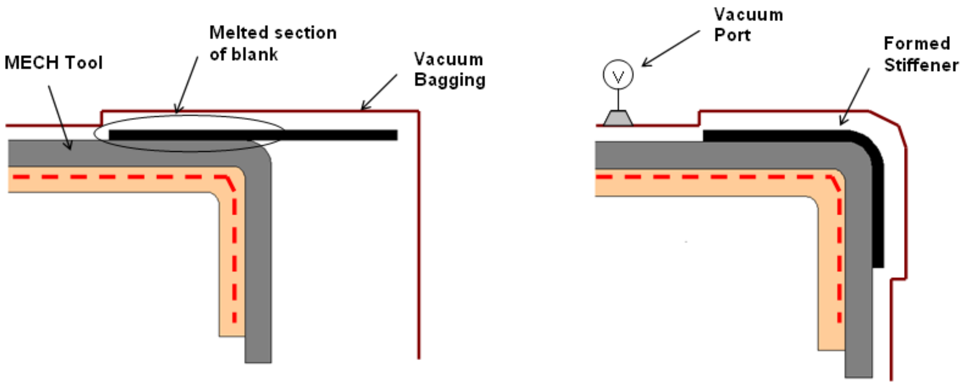

Figure 5: (Left) Stiffener blank is positioned overhanging on MECH™ Tool (Right) Tool is heated, vacuum applied and stiffener is formed

The use of vacuum only processing for long constant-section stiffeners is an extremely quick and simple method of manufacturing stiffeners. The heat is applied at only the location to be melted and as the vacuum bagging can be reused there are effectively no consumables or waste materials from processing.

The resulting stiffeners form without fibre wrinkling or misalignment and consolidate to the same quality as the flat laminates. A micrograph of a radius of a formed L-section stiffener is shown in Figure 6.

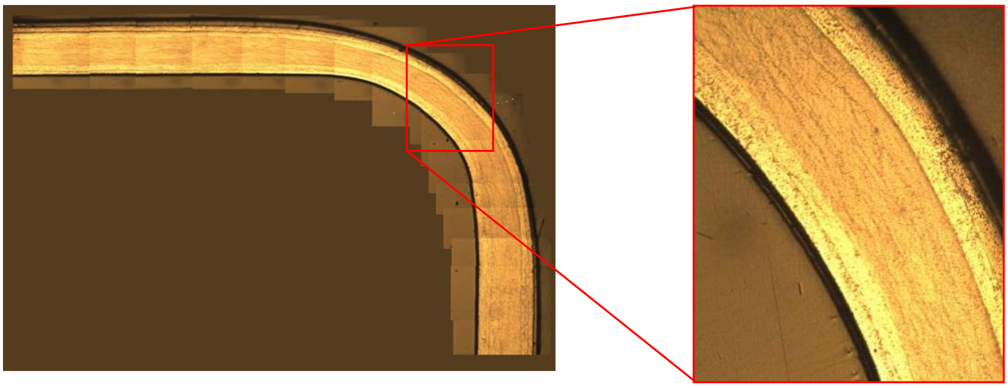

Figure 6: Micrograph of formed L-section stiffener radius

2.4 Assembly

The re-designed panel takes advantage of the ability of thermoplastic composites to be fusion bonded. Replacing the integrally moulded stiffeners of the original structure, the stiffeners were individually formed and bonded to the curved base panel using the Amorphous Interlayer Bonding (AIB) technique [4].

The method involves placing an amorphous film, Polyetherimide (PEI), at the interface of the bond. The parts are held in contact under pressure and locally heated to a temperature above the melt temperature of the PEI film but below the melt temperature of the PEEK. The PEEK is not melted and retains its structural integrity during bonding. The process window for AIB is shown in Figure 7.

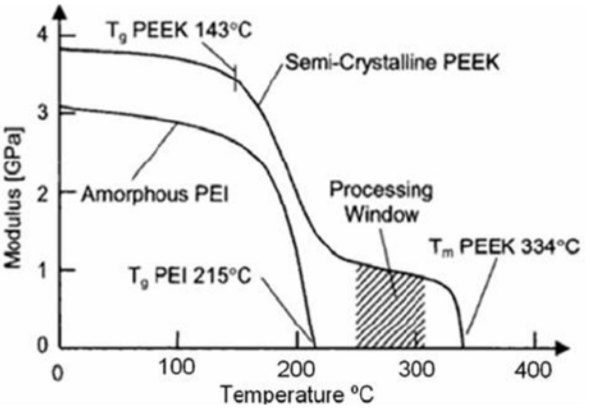

Figure 7: Process window for Amorphous Interlayer Bonding [5]

The PEI film is placed on top of the laminate stack when kitting and is consolidated with the CF-PEEK. A cross-section through a typical laminate with PEI is shown in Figure 8. An electrically heated assembly fixture is used to fuse the components together.

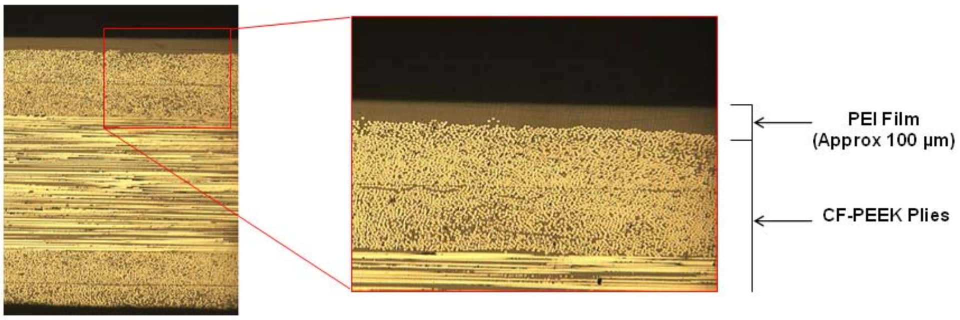

Figure 8: Cross-section through laminate showing PEI film layer

3.0 Testing

A multi-stiffener panel was designed and manufactured to verify the load carrying capability of the structure. The panel consisted of 4 T-section stiffeners with approximate dimensions 400mm x 300mm. The ends of the test specimen were potted in resin to allow for accurate machining and alignment during the test. The test panel is shown in Figure 9.

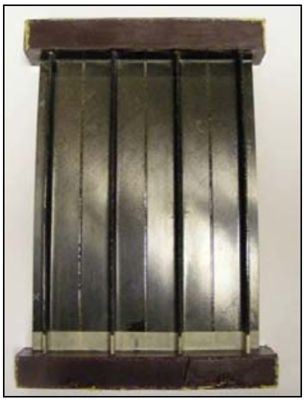

Figure 9: Multi-stiffened test panel

The panel was tested in uni-axial compression using a Zwick universal test machine. The results for load versus displacement are shown in Figure 10.

Figure 10: Graph of load versus displacement

The panel displayed a linear response to the load until 250 kN was reached. At this load level the stiffeners buckled significantly. The panel collapsed at 265 kN. Images of the panel at 240 kN, 250 kN and 265 kN are shown in Figure 11.

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Figure 11: Images of panel at 240 kN, 250 kN and 265 kN (respectively)

The panel exceeded the design load and reserve factor required for the structure.

4.0 Full Scale Manufacture

The full scale demonstrator was manufactured by consolidating the base skin and thermoforming the stiffeners separately. The consolidated base skin is shown in Figure 12.

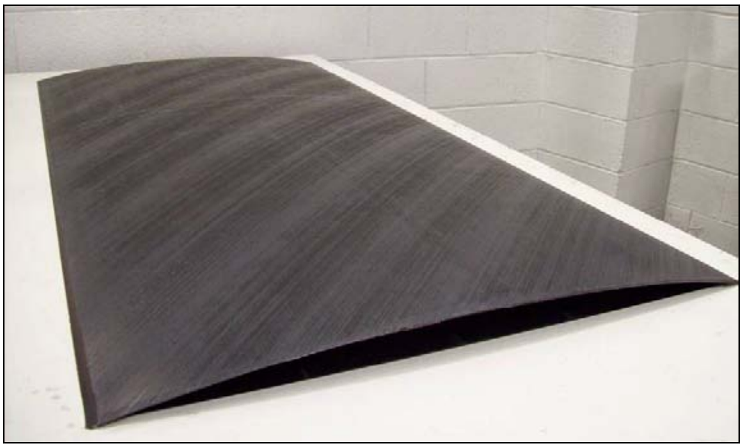

Figure 12: Consolidated skin panel

The assembly of the demonstrator was performed on the MECH™ Tooling. The assembly operation used vacuum pressure only applied through the use of alignment fixtures and vacuum bagging. The completed demonstrator is shown in Figure 13.

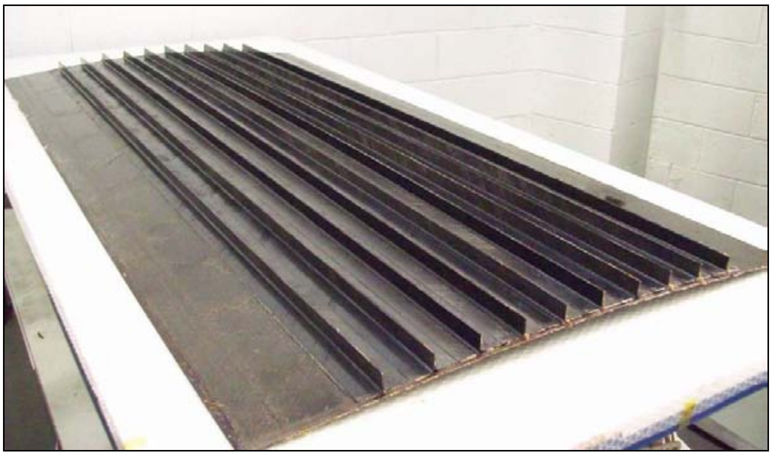

Figure 13: Assembled demonstrator

5.0 Conclusions

This paper presented methods of manufacture for aerospace structures up to 2 metres in length using Out-of-Autoclave processing of thermoplastic composites. A section of the 2/3 interstage of the Ariane 4 has been re-designed in thermoplastic composites for a manufacturing demonstrator using bonded L-section blade stiffeners.

The MECH™ tooling system has been shown to be capable of consolidating carbon fibre/PEEK panels using vacuum processing. A novel stiffener forming method has been proven to thermoform stiffeners up to 2 metres in length. An assembly method for bonding stiffeners has been presented and stiffened panels tested to validate the predicted buckling performance.

A large scale demonstrator has been assembled to further verify the suitability of the process for large space structures.

6.0 Acknowledgements

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7.0 References

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