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Project

LESSON

Title

Executive Summary Report

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1 Scope and General Aspects

This document concisely summarises the findings of the de-risk activity LESSON.

2 Terms and Definitions, Abbreviated Terms and Symbols

CFRP	Carbon Fibre Reinforced Polymer
I/F	Interface
LESSON	LargE Scale Struts prOductioN
SPS	Space Structures GmbH
VRTM	Vacuum Resin Transfer Moulding

3 Introduction

The targeted product of the LESSON activity was the existing full-CFRP struts **SpaceStrut™** with continuous carbon fibres shown in Figure 3-1.

Figure 3-1: Space Structures's SpaceStrut™ family

The unique properties of this product are:

- **Full CFRP**. including the interfaces, with continuous carbon fibres
- **Maximum ultra-lightweight**. 50 - 80 % mass saving depending on length
- **Dimensionally stable**. No thermal expansion, insensitive to thermal cycling. Special **DoubleZero™** variant with zero CTE and CME. CTE can also be customised.
- **Reduction of number of parts**. By possible integration of attachment brackets into strut design

The production process of full-CFRP struts, formerly only suitable for low volume production rates (~10 struts/month) and including worker safety critical processes, was reviewed and changed to enable production rates >100/month and improve worker safety.

Capabilities developed at Space Structures GmbH in this activity are:

1. Design and manufacturing of temporary, water-soluble tools suitable for liquid resin injection
2. Room temperature, out-of-autoclave, liquid resin injection
3. Dissolving process for temporary tools that need to be extracted via small openings in the part.

Applications that are linked to the technical objectives are mainly high parts quantities applications like satellite constellations, launchers and other applications outside space, e.g. aircraft.

The developed manufacturing technology is suitable for many applications. Primary, secondary, tertiary structures, high loading (e.g. 100kN), high stiffness, zero thermal expansion. Temperature range up to +110°C, low temperatures are straight-forward until at least -160°C and beyond. The results of this activity are pertinent to ESA programmes such as VEGA E, where significant mass savings could be achieved. A CFRP boom for the comet chaser mission has already adopted the developed technology. 2 CFRP booms were manufactured and successfully tested.

4 Main Results

4.1 Design for 2 applications

Two example applications were chosen for the demonstration and validation of the optimized manufacturing process. After selection of the applications, requirements were defined in cooperation with the agency, either general or specific to one application or the other. Based on the requirements, designs for both applications were developed. Breadboard A consists of a CFRP strut with metal bushings and Breadboard B consists of a CFRP strut with a bonded threaded metal insert on both ends into which a rod spherical bearing will be attached. The items have been sized and designed to comply with the requirements.

Table 4-1: Breadboard Overview

Application	I/F Distance	Weight	Outer Diameter	Design Load
Breadboard A: Secondary structure moon lander	348 mm	93 g	Ø 28 mm	14.33 kN
Breadboard B: VEGA SSMS dispenser strut	875 mm	733 g	Ø 60 mm	22 kN

4.2 Generic manufacturing process

An optimised generic manufacturing process has been developed suitable for the production rates >100/month and improved worker safety. The resulting process concept is a VRTM process combined with additively manufactured inner and outer moulds for maximum flexibility and short project timelines. The design and materials of the to-be-produced items relied completely upon heritage from Space Structures' SpaceStrut™ product family.

Figure 4-1 gives an overview of the different steps of the manufacturing process.

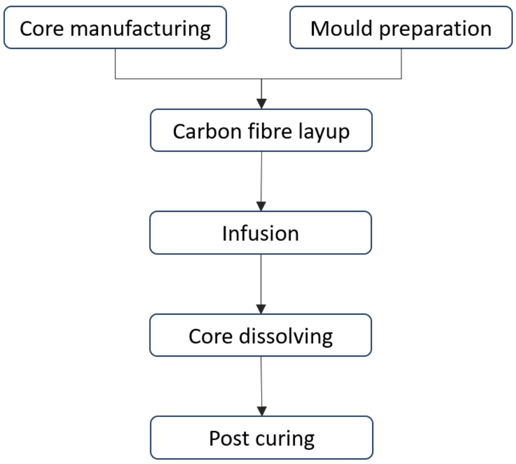

Figure 4-1: Manufacturing process

Core manufacturing: The core for the VRTM process is made of a soluble material. The ends depend on the lug geometry of the actual part to be manufactured. The core is composed of multiple parts that are glued together. The surface of the cores is sanded and then coated.

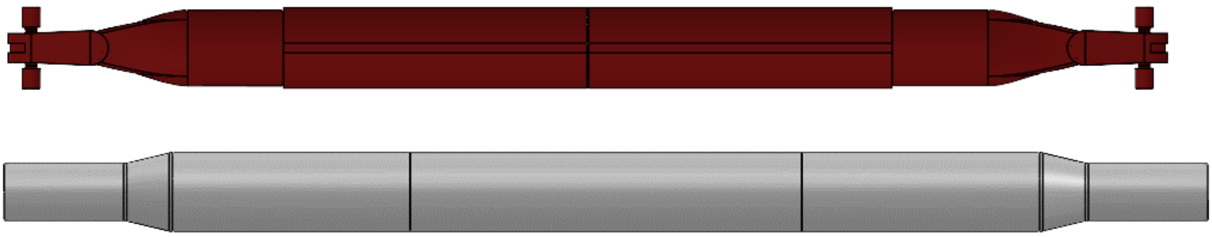

Figure 4-2: Breadboard A core (top) and Bread B core (bottom)

Mould preparation: The moulds consists of multiple parts that are either additively manufactured or milled. These are then combined into two halves using liquid silicon. The liquid silicone is then also applied to the gasket groove present in the mould and allowed to cure for 24 hours. For future projects, the usage of liquid silicone will be completely replaced by Silicone or Nitrile rubber gaskets and fasteners. This would save a lot of time because it avoids the 24-hour curing time for the liquid silicone and also avoids a lot of cleaning which the liquid silicone requires. First preparation step is the thorough cleaning of both halves, and the removal of any leftovers from prior infusions. Next is the repeated application of a liquid solvent-based release agent.

Carbon fibre lay-up: The Breadboards are made up of preforms that are a combination of fibres in unidirectional (UD) orientation and ±45° Carbon Fibre fabric. The fibres are laid into a shape dictated by the design of the Breadboards and then stitched on to a fabric holding the fibres in place and making it easier to handle. The different preform sub-layers are wrapped around the core one by one with the aid of an aerosol spray glue. The preforms have an overlap to allow continuation of the fabric to avoid failures at the overlap areas. The overlap must be at least 3 times the wall thickness.

Figure 4-3: Carbon fibre preforms

Infusion: The core along with the wrapped preform is placed into the mould. and the mould halves can be closed. The mould can be heated to 30 degrees to help improve the flow if the resin since it has a lower viscosity at higher temperatures. 30 degrees allows for the core to also not destabilize during the process.

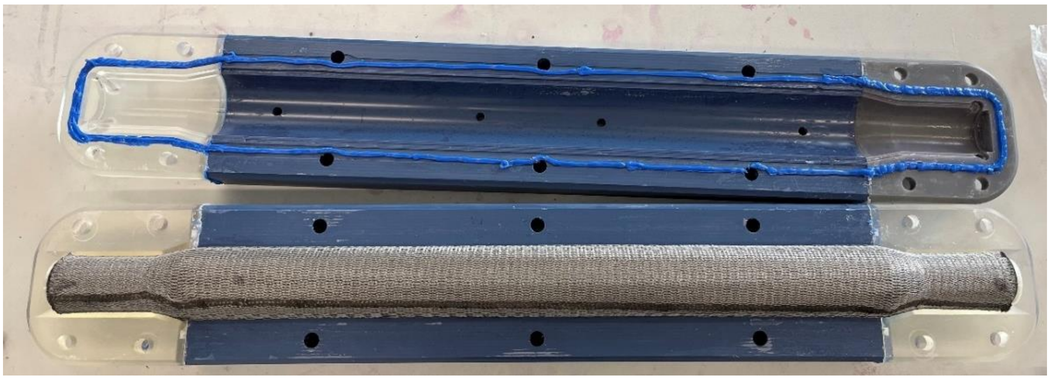

Figure 4-4: Part placed in mould ready for infusion

Once the mould is sealed and leak-checked, epoxy resin system Araldite LY5052/Aradur 5052 is prepared by thorough mixing and degassing. The vacuum lets the resin flow into the part. The resin is then left to cure for 24 hours at room temperature and then the part is demoulded and inspected. To repair any dry patches, a localized vacuum bag can be made around the dry fibres and infused again.

For struts of smaller sizes, it is possible to infuse the fibres with the resin flowing along the length of the part. For bigger parts, it was devised to create resin channels on either side of the tubes with multiple inlets and have the outlets at 90° to the channels. This would make sure that the resin must flow through the fibres to reach the outlet, leading to more successful infusions.

Core dissolving and post curing: Once the part is fully infused, the ends of the cores are cut off and the part is placed into the wash setup to dissolve the core. A water pump allows for the use of a closed process where the water is heated and introduced inside the part and cycled until the core fully dissolves. The following optimal process parameters were determined:

- core wall thickness of 1.2mm minimum
- core surface is coated with core material-water-solution
- dissolving by warm pump agitated water

After dissolving of the core, the complete part is visually inspected and heated for 4 hours at 100°C to reach full cure.

4.3 Manufacturing and Testing of breadboards

Five breadboards each for both applications were manufactured and tested. Material tests confirmed that the development and manufacturing process results in material properties in line with the requirements, see Table 4-2.

Table 4-2: Material test results

Property	Target	Avg Test Result
Glass transition temperature	≥110°C	120°C
Fibre volume content	55% ±5%	< 55%
Porosity	<2%	1.2%

Figure 4-5: Breadboards (top: Moon lander application, bottom: Vega SSMS Strut)

Breadboard A – moon lander secondary structure: All 5 breadboards successfully passed visual, mass and electric conductivity tests. Visual inspection confirmed quality of the infusion process and complete removal of the soluble core. Mass of the breadboards is within ±5% of predicted mass and well under the maximum mass of 110g. A custom drilling jig is needed to respect the hole-to-hole length requirements. All breadboards went through tension-compression test and survived limit load without exception. All fully infused breadboards (4/5) survived 1.5 x limit load, i.e. ultimate load. Axial stiffness is above minimum requirement for all strut in tension and compression. **Test results proofed the maturity of design and processes for the chosen application.**

Breadboard B – VEGA SSMS dispenser strut: All 5 tested struts passed the complete test campaign. Quality of the infusion process and complete removal of the soluble core was confirmed. Measured mass of all struts is close to the predicted mass of 733g (exl. bearings) and therefore about 1000g lighter than their aluminium counterparts each. Struts can be made to be either electrically conductive or isolating. All struts are conforming with dimensional requirements and survived ultimate load in tension and compression without any abnormalities. Axial stiffness is far above the stiffness of the aluminium struts. **Test results prove the superiority of the CFRP struts over the aluminum struts currently in use for the SSMS dispenser with lower mass and higher stiffness.**

5 Conclusion

In the frame of the de-risk activity LESSON, breadboards for 2 different applications have been designed, manufactured, and tested:

- Breadboard A - secondary structure strut for a moon lander and
- Breadboard B - a lightweight CFRP alternative to the current VEGA SSMS dispenser strut made of aluminium.

The optimized manufacturing process was presented, and the main finding of the activity were summarized.