ADVANCED LIQUID RESIN INFUSION - A NEW PERSPECTIVE FOR SPACE STRUCTURES

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ABSTRACT: To reduce composite manufacturing costs, an optimised liquid resin infusion technology has been developed at the DLR Institute of Structural Mechanics in order to manufacture high performance composites with excellent laminate and surface quality at reasonable costs. Apart from the laminate quality, priority was given to a reduction of preparation and lay-up efforts and a reduction of raw material costs. To achieve these goals, a combination of dry fibre preforms and autoclave technology showed the best results. This technology known as Single Line Injection-RTM (SLI-RTM) proved its potential especially for a small and flexible series production or prototype manufacturing in several applications.

1 MANUFACTURING OF COMPOSITES

With the exception of filament winding structures, high-quality, continuous fibre-reinforced components are currently being industrially manufactured with the prepreg method. However, due to rising production costs, research on the so-called liquid resin infusion method (LRI) has intensified lately since this method promises a significant reduction in manufacturing cost.

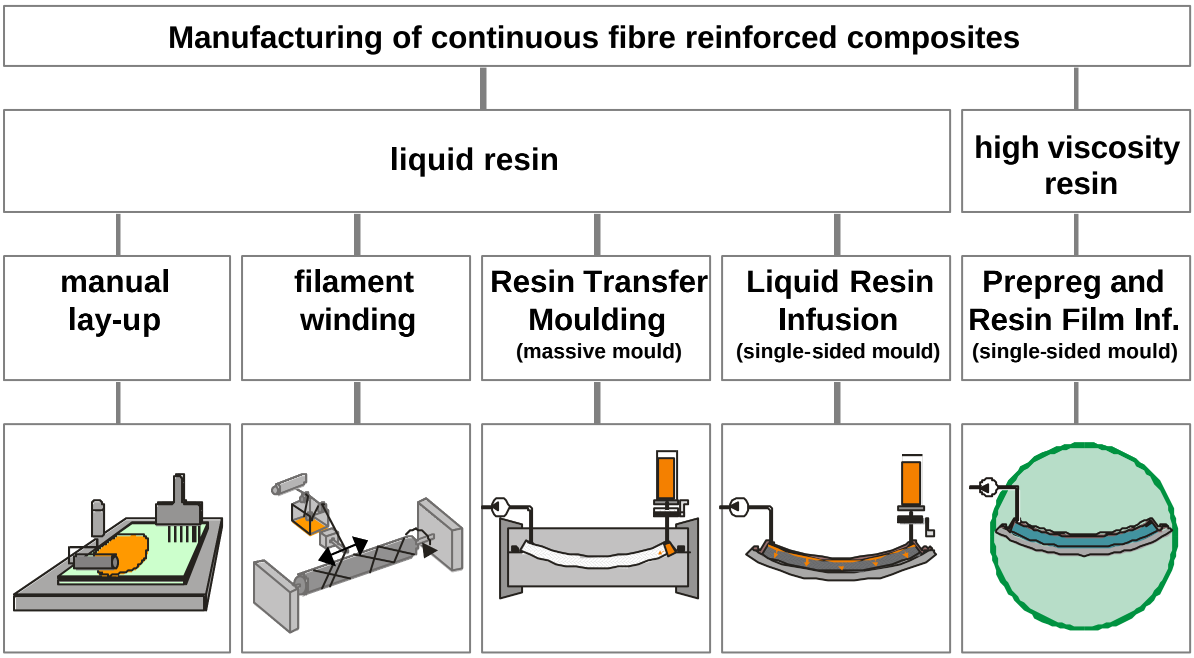

Fig. 1: Composite Manufacturing Technologies

1.1 The Prepreg Autoclave Technology [2]

At present, the prepreg autoclave method is primarily being used for the manufacture of high-quality composite components since it provides a very high and reproducible component quality while requiring a moderate investment of tools. The high component quality is attained by compacting the prepregs (resin impregnated, continous fibre products), in the autoclave. Simple tools are required because only single-sided supporting tools are needed which have a flexible vacuum cover. However, prepregs are costly due to their specialised manufacturing process. In addition the lay-up process with prepreg is more complicated than with dry fibre material.

1.2 The Resin-Transfer-Moulding Method [2]

The Resin-Transfer-Moulding (RTM) method has become established in the past few years as an alternative to the Prepreg Autoclave technology. In this method, a cost-effective and non-impregnated fibre preform is placed in a massive mould to which a low-viscous resin system is injected under pressure. The considerably lower costs of the semi-finished products are advantageous here when the manufactured quantity warrants the enormous investment costs for the vacuum-tight, temperature-adjustable, pressure-loaded, and often very complex and heavy moulds. Since a compacting of the laminate which is even and expandable in all directions is not possible in massive RTM moulds, a reduction in the quality of the laminate and fibre content must be expected.

1.3 LRI / SCRIMP Technology

A promising subtype of the LRI (Liquid Resin Infusion) technology is the SCRIMP method. In the SCRIMP (Seeman Composites Resin Infusion Moulding Process) method a flow aid is applied to the dry fibre perform that enables a quick distribution of the resin over the parts surface during infiltration. As opposed to RTM methods, the infusion and curing process take place at ambient pressure. In contrast to classical LRI methods, the infiltration of the resin takes place perpendicular to the flat fibre reinforcement. Normally, a single-sided mould is also used here which is sealed with a vacuum bag. Because of the low fibre compacting as well as uncontrolled resin distribution, the quality of the laminate is usually considerably lower than with the Prepreg Autoclave method.

2 THE SINGLE LINE INJECTION (SLI) METHOD [3]

Since the quality and economical manufacture of fibre composite components play decisive roles in their successful introduction into the market, a manufacturing process was developed at the Institute of Structural Mechanics with the goal of producing high-quality fibre composite components with the best possible laminate and surface quality in a cost-optimised production process. The process was to be optimised for the production of small series and prototype components with a quantity of up to 500 pieces per year since a great market potential is developing in the areas of aircraft, railway, and vehicle prototype construction.

2.1 The Principle of the SLI Method [3]

The approach for the development of the SLI method essentially is to combine the advantages of the raw material of the liquid resin technology with the laminate quality of the Prepreg Autoclave technology. The advantage of this method in comparison to the LRI method is that the resin is injected under pressure and that the laminate can be compacted by the autoclave pressure. The name of the method is an indication that the evacuation of the fibre preform as well as the injection of the resin system is carried out with the same resin transfer line. This resin transfer line can be arranged on the fibre preform in any arrangement to shorten the flow path and, with that, the injection time.

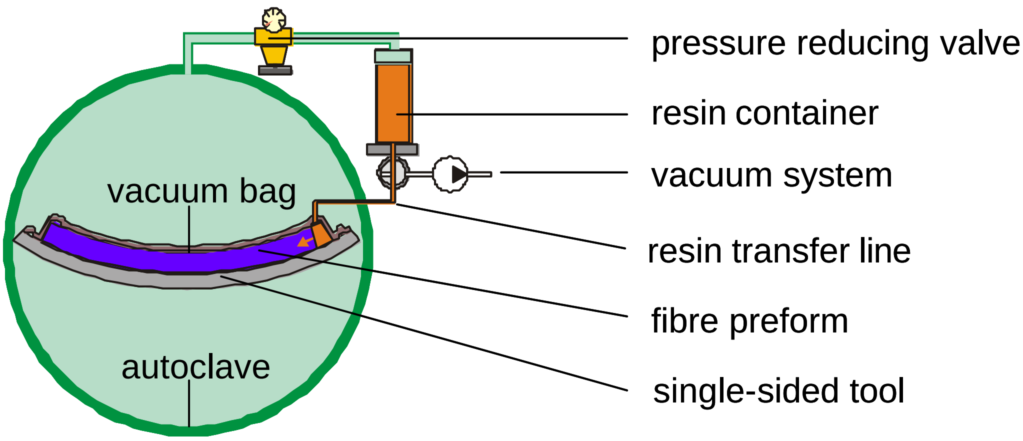

Fig. 2: Depiction of the SLI Method

With the SLI method, it is possible to combine cost-effective and dry semi-finished fibre products such as fabrics, weaves, and warp knitted fabrics with the optimal matrix resin for each application. In addition to the standard epoxy resins, vinyl ester resins, polyisocyanurats (Blendur), heat-resistant resins such as bismalimide, cyanate ester and even phenolic resins can be processed. The excellent and void-free laminate quality achieved by the Autoclave Process leads to a superb component quality which almost reaches the status of a Class A surface.

2.2 Variation of the Fibre Volume Content

An additional characteristic of the SLI method is the possibility to directly influence the fibre content by means of the process parameters. This is possible because the flexible side of the mould enables the autoclave pressure to be in equilibrium with the inner resin pressure of the component and the restoring force of the fibre material. If the autoclave pressure is adjusted to be the same as the inner resin pressure, the fibre material can relax in the thickness direction and can support the impregnation due to greater permeability. If the fibre preform is completely impregnated, the autoclave pressing on the fibre material can be selectively increased by reducing the injection pressure until the desired fibre volume content of typically 60% is reached.

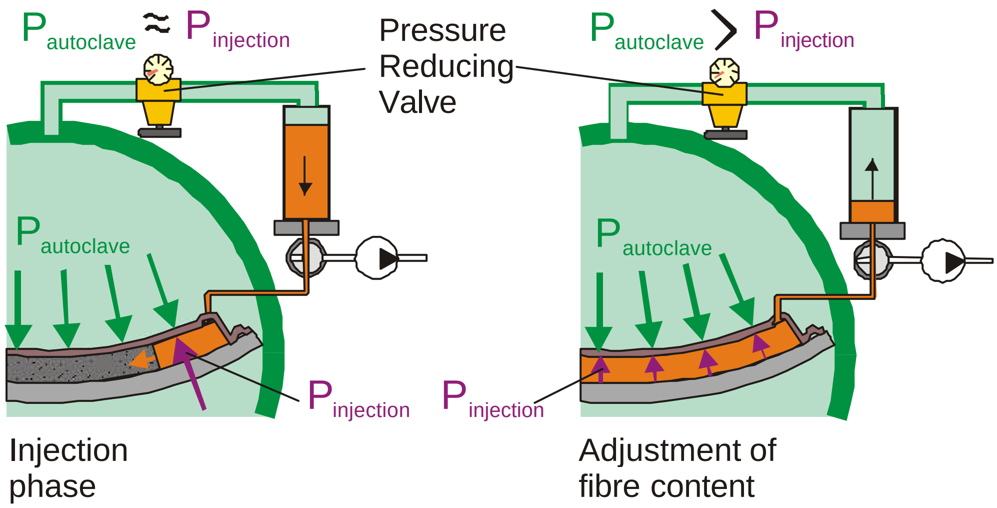

Fig. 3: Pressure distribution during injection and adjustment phase

4 APPLICATION OF THE SLI TECHNOLOGY

During the last 4 years more than 2500 parts have been successfully manufactured in SLI Technology. Most of the structural parts where designed as highly integrated monolithic or sandwich structures. In case of the sandwich structures Rohacell PMI foams showed the best structural performance and they can be worked in 180°C production processes after being appropriately tempered. The high degree of compressive strength of medium weight PMI foams makes it possible to apply autoclave cycles with more than 0.5 MPas at temperatures of 180°C, meaning they are suited to standard Prepreg and SLI production cycles.

4.1 The Solar Sail Project

Within the “Solar Sail” project the DLR Institute of Structural Mechanics was responsible for the manufacturing of the boom structure. The boom structure had extremely weight critical requirements meaning that only the finest Prepreg available was able to meet the demands. For the processing of this special Prepreg a thermal expansion compatible tool had to be applied. To reduce the tooling costs a CFRP tool manufactured in SLI Technology was chosen, because the void free laminate quality ensured a sufficient gas tightness and a smooth surface without any additional surface treatment.

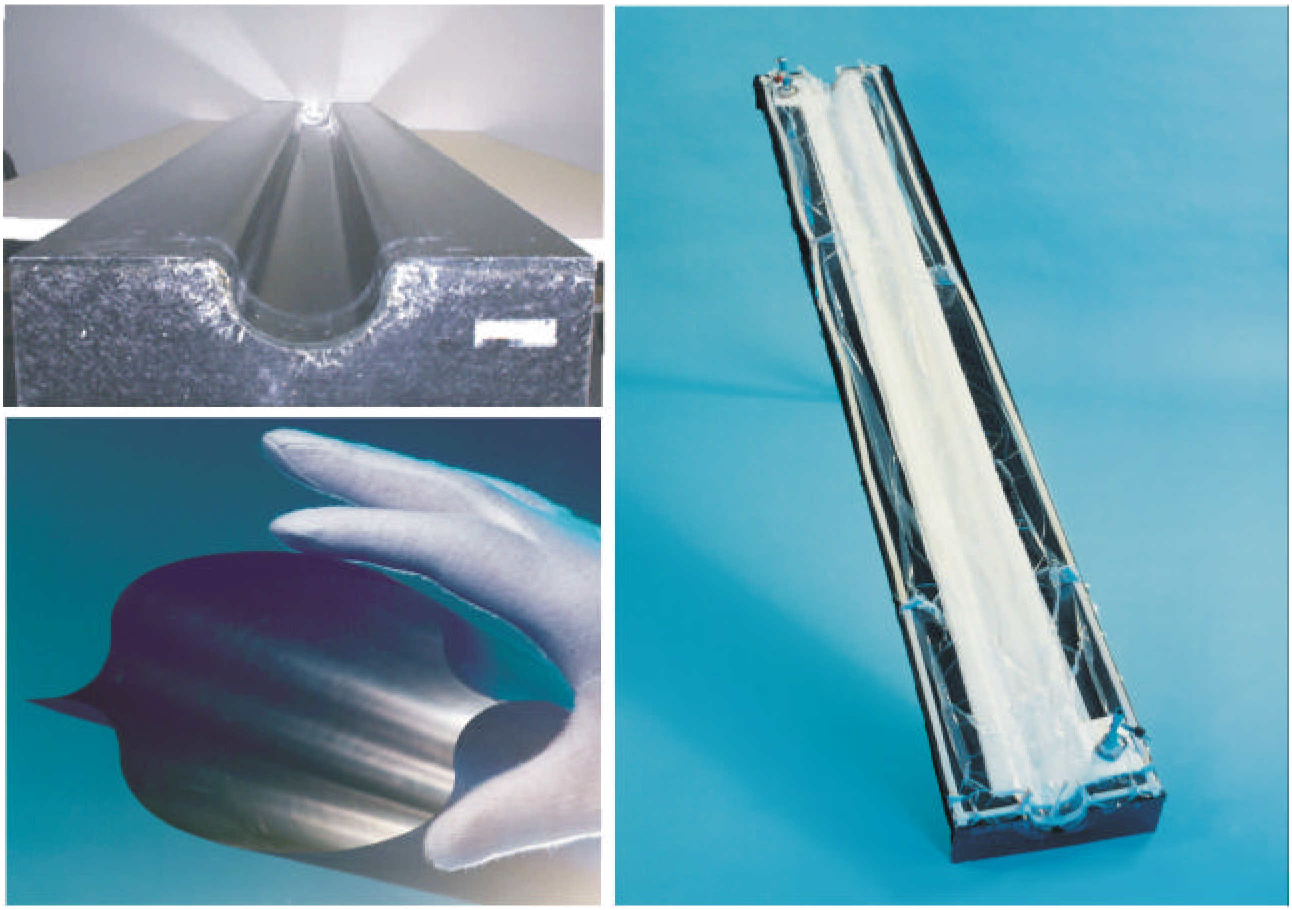

Fig.4: CFRP tooling for the “Solar Sail” boom manufacturing

The highly complex “Solar Sail” deployment module was designed and manufactured by the INVENT Company. The INVENT Company is a licensed user of the SLI Technology and highly experienced in the field of efficient manufacturing concepts. One of the requirements of the deployment module is the maximum Volume of 0,6m x 0,6m x 0,7m in a retracted configuration. With expanded booms the Sail covers an area of 20m x 20m. The boom rotor, the base plate and the sail boxes are designed as foam sandwich structures with integrated inserts for load introduction.

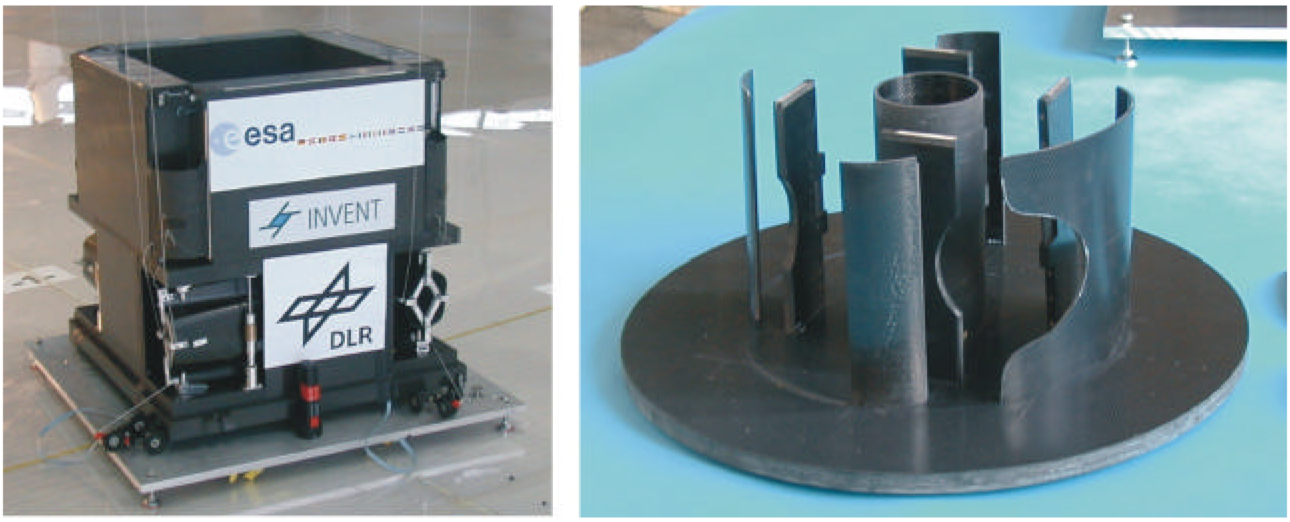

Fig.5: Deployment module

4.2 Nose Landing Gear Doors for the Fairchild Dornier 728 [3]

Based upon the experiences in manufacturing the „Solar Sail deployment module“ for Esa Estec and various Class III Fairings for the Fairchild Dornier Do 328 Jet, INVENT was able to assert itself against established international suppliers with the Nose Landing Gear doors and the RAT (ram air turbine) door for Fairchild Dornier’s Do 728 regional jet. Right from the start the production of the very first component set confirmed that using a fibre semifinished product with draping properties and a precisely prefabricated foam core with locally adapted densities is successful both with regard to production times and the costs of the semifinished products. In case of the Nose Landing Gear Door and the RAT Door, the applied Rohacell PMI foam core is designed as a structural sandwich element and also as effective Manufacturing aid. In case of the Fairchild 728 the decision to use foam cores instead of honeycomb cores for this application was a clear customer requirement coming from a major airline. The contribution of the DLR institute of Structural Mechanics within the Fairchild 728 Project was the development of an effective tooling strategy where several components are simultaneously infiltrated.

Fig. 6: Nose Landing Gear Doors of the Fairchild Dornier Do 728 with Rohacell foam cores

5 FUTURE CFRP OPTIMISATION CONCEPTS [4]

Since 1995 the DLR Institute of Structural Mechanics is investigating new manufacturing concepts using optimised fibre products in combination with LRI technologies. Within these activities a number of demonstrator components have been manufactured using a variety of different densities of Rohacell PMI foam cores because in many cases sandwich structures are the key to efficient lightweight design . The primary goal of increasing the performance of foam core components was improving shear strength and increasing the quality of the core-skin interface.

5.1 Foam cores as a manufacturing aid [4]

To reduce manufacturing efforts foam cores can be used as a production aid when being combined with dry fibre semifinished products. To achieve this, the foam cores can be wrapped with the required dry fibre semifinished products (fabrics, warp knitted fabrics, etc.) or hose-like semifinished products can be used such as braided tubes. An UD fabric product developed by "von Bauer" is especially adequate to this purpose because it makes it possible to handle the sandwich preform excellently with the aid of a elastic Lycra weft thread worked in. The advantages of this strategy were demonstrated with innovative fuselage designs developed within the HGF black fuselage project[ref. 3].

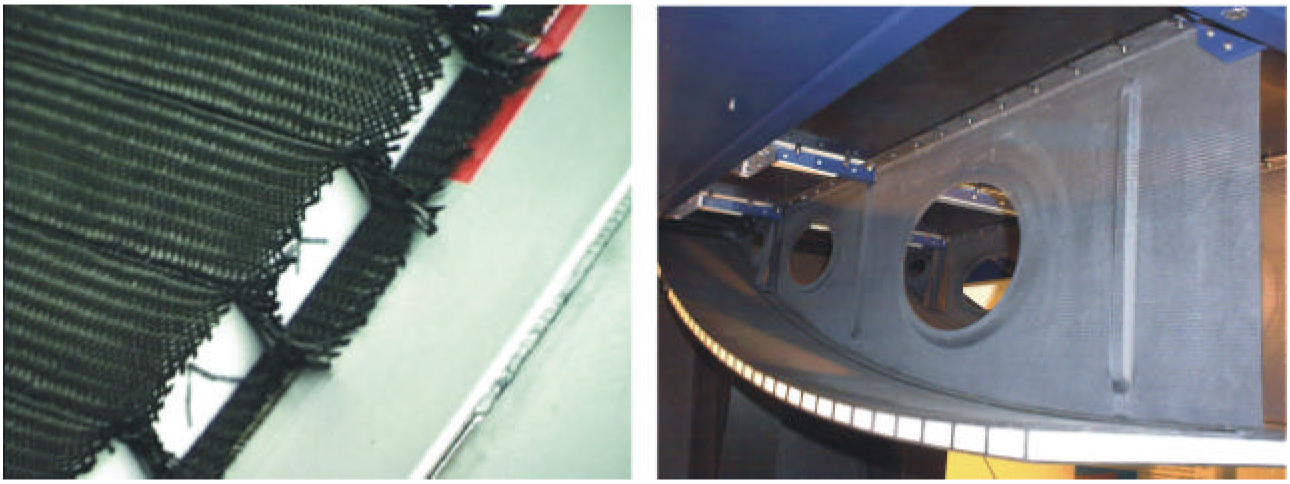

Fig.7: HGF project "Black Fuselage" design demonstrator

5.2 Shear Strength and Skin to Core Interface Optimisation [4]

Increasing shear strength is an important approach for extending the range of applications of foam sandwich components to heavily loaded light weight structural components. Since a high-quality PMI foam core can only be improved in its performance by increasing its density, it is essential to find a way to combine foam cores with a fibre reinforcement. A structurally very successful method is integrating thrust webs under 45° whose dimension can be adapted to the expected stress [ref. 5]. An excellent interface between foam core and skin is also of significant benefit to impact and crash critical applications. A possible approach is to use fibre reinforcements in z-direction to optimise the interface behaviour between the surface skins and the foam core. An elegant method for accomplishing a z-directional fibre reinforcement is the single-sided stitching technique where loops of stitching thread are inserted through the surface skin and into the foam core using a flexible single-side stitching head [ref. 4]. After infiltrating the component during the autoclave process, the thread loops are impregnated with resin and after that consolidated in the curing process.

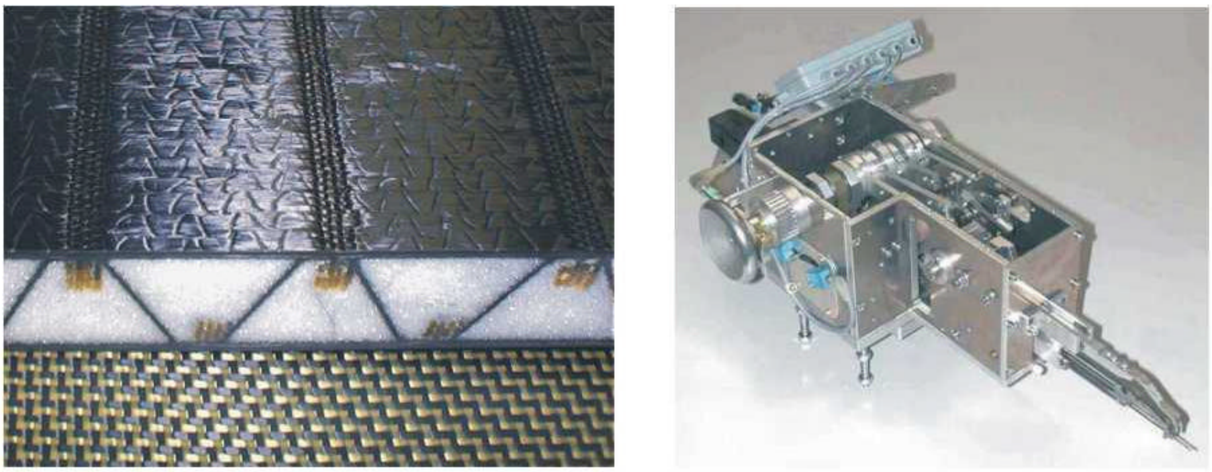

Fig. 8: Shear Optimised, Sewed Sandwich / Single-Side Stitching Head (KSL, Lorsch)

5.3 Structural Interface Optimisation [6]

Although it is recommendable for composite structures to chose a highly integrated, fibre adapted design structural interfaces can not be avoided completely. Even though bolted joints are not ideal for composite structures they are widely used within the aeronautical industry. To improve bearing performance of composite structures it is possible to combine carbon fibres with thin layers of specially prepared titanium sheets. As a result of this approach the thickness of the laminate can remain constant because doublers used for stress reduction in the interface area are no longer necessary. To show the potential of CFRP/Titanium hybrid laminates this concept was used for the main structural interfaces of the "black fuselage" demonstrator. This demonstrator shows different innovative design and manufacturing concepts for future fuselage structures and was part of the HGF (Hemholzgemeinschaft deutscher Forschungseinrichtungen) Project "Schwarzer Rumpf" .

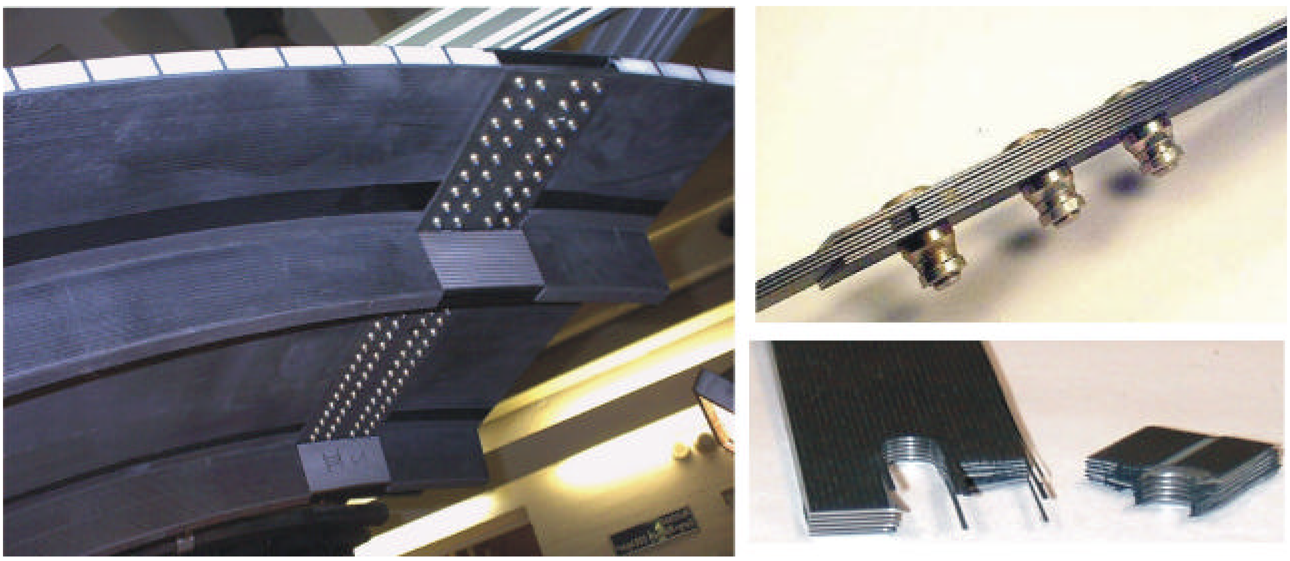

Fig.9: CFRP-Titanium hybrid laminate

6 CONCLUSION

The Liquid Resin Infusion technology has the potential to extend the field of composite applications because manufacturing costs can be significantly reduced. That is mainly, because less expensive and less storage critical semi finished products and effective textile technologies can be applied. Apart from a pure cost reduction it is also important to ensure a high and reproducible laminate quality because this is essential for successful lightweight designs. The experiences with the Single Line Injection Technology proved, that it is possible to combine cost effectiveness with high laminate quality for qualified space and aeronautical applications. Current research activities of the Institute of Structural Mechanics concentrate on innovative performing concepts for highly integral and fibre adapted structural designs. In addition the short comings of foam core based sandwich structures and heavily loaded interfaces shall be reduced to a minimum.

7 REFERENCES

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