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RESIN TRANSFER MOULDING OF HIGHLY LOADED CARBON FIBRE COMPOSITE AIRCRAFT SPARS USING NOVEL FABRICS AND TOW PLACEMENT TECHNIQUES

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SUMMARY

A BAE Systems / UK EPSRC funded project Flaviir, is investigating the design and manufacture of low cost carbon fibre composite airframe structures. Novel binder coated unidirectional fibre tapes and tows were developed to enable the design of optimised primary structures. The RTM technique was applied to mould net shape sections of spar components. Various designs of wing attachment lugs were manufactured with a range of reinforcement materials, including non crimp fabric, novel binder coated tapes and conventional unidirectional prepreg. Alongside these, a novel technique termed optimised tow lay up; OTL was used to reduce the weight. Binder coated carbon fibre tow is placed around the structure in the principal stress directions to increase both bearing strength and overall component stiffness. The novel materials, manufacturing technique and initial element test results are presented.

1. INTRODUCTION

The manufacture of lightweight carbon fibre composite structure is highly effective and affordable for simple geometry components, such as wing skins, control surface and access panels. For components which have more shape complexity, the cost of moulding and assembly can be prohibitively costly. This results from the tooling cost for bonding or co-curing of small parts and the thickness tolerance required to enable parts to be bolted together. Consequently, the high speed machining of aluminium is the preferred approach for aircraft internal fuselage structure. However, the weight saving potential for highly loaded, complex shape internal structure through the use of carbon fibre composite encourages the investigation of new composites moulding technology. The design of highly loaded components is dominated by joining issues for which the use of locally thickened, bolted webs and lugs is not weight efficient and very costly. Consequently, an investigation of the design and manufacture of a highly loaded fighter aircraft fuselage frame using novel lay up design, utilizing fibre steering, and moulding technology was set up.

2. OBJECTIVES

The objectives of the study were as follows:
Development of a preforming and moulding technique for a fully co-infused, net shape spar with complex design features.

Design of wing mounting lugs using the technique of tow steering to optimise fibre lay up angles for increased bearing strength and hence weight saving.

3. SPAR DESIGN

By considering metallic spar designs from current aircraft with similar roles, (an example is shown in figure 1.) a generic spar design was conceived. It incorporates attachment lugs, skin attachment flanges, stiffeners and apertures / access holes, shown in figure 2. The unusual curved shape, large apertures and heavily loaded attachment points are essential for the aircraft role being considered and accentuates the potential benefits of fibre steering to maximise the stiffness of a curved beam.

Figure 1. Metallic spar used in Lockheed's F22

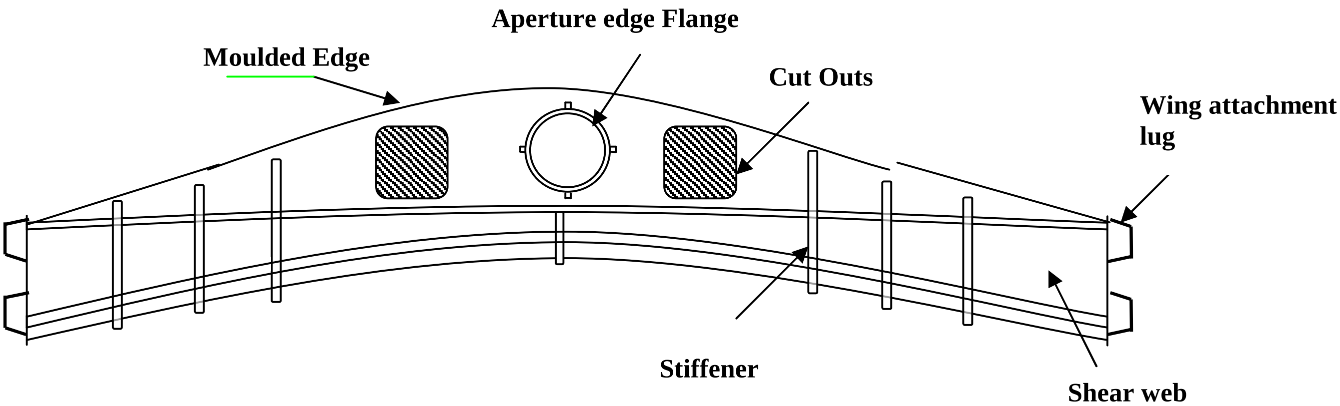

Figure 2. Generic carbon fibre composite spar design scheme

There are several design challenges for the spar which include:

- Provision of sufficient stiffness for the curved shear web.
- Joining / integration of the stiffened spar flanges to/with the wing attachment lugs.
- Joining / integration of the stiffeners to the attachment lugs

Since the component's fibre lay up design is complicated by the curvature and the lugs, the standard laminated fabric approach is not as efficient for the provision of strength and stiffness as it would be for standard skins and shear webs [Ref 1 and 2.] Figure 3. shows the reduction in laminate strength with misalignment of the fibre and loading angle.

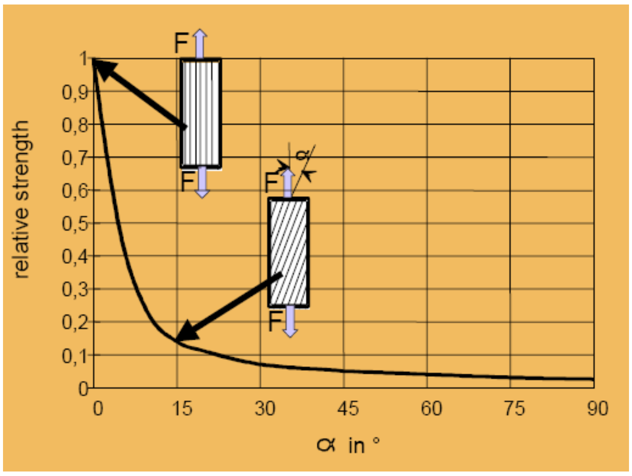

Figure 3. Variation in laminate strength with the angle of applied load

In place of fabric lamination, an alternative design uses carbon fibre tows placed in prescribed shape paths aligned with the directions of principal stress. This concept was first discussed by Matteck [Ref 3.] who studied the strength optimisation of natural structures such as trees and animal bones. In its simplest form this linking of loads through the placement of fibres along the principal stress directions is shown by Temmen et al [Ref 1.] Applied to a double lugged aircraft tail plane connection beam shown in figure 4 , the rovings simply replace carbon fibre fabrics with a resultant strength increase of 60%. The principle has been practically applied to the manufacture of robot arms and bicycle frames though the use of a robot tow application and stitching system, but not optimised for attachment strength [Ref 4.]

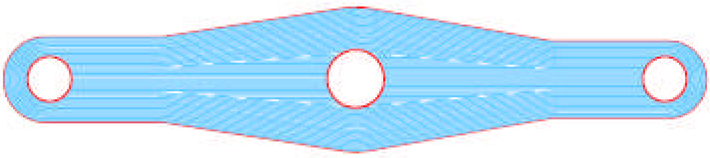

Figure 4. Optimisation of roving for a connection beam for the tension load case. (from Temmen et al Ref. 1.)

The challenge was to take the placed tow principle and investigate its application to the complexity of the fuselage frame design.

4. TEST ELEMENT DESIGN AND MANUFACTURE

The design and moulding development was planned in several stages, the first addressing the shear web and wing attachment lugs. Figure 5. shows the first stage design. To provide dimensional control for assembly, the resin transfer moulding (RTM) technique was selected.

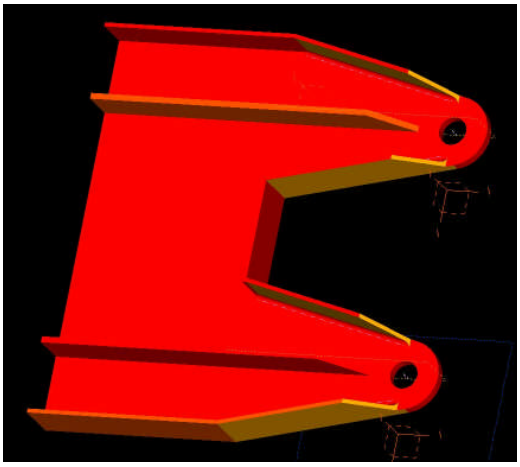 Plate thickness 10mm, hole diameter 20mm

Figure 5. Frame shear web and attachment lug – 1st stage design

The initial test elements were the individual lugs themselves so as to establish the bearing strength of various lug design and manufacturing approaches. To enable this, a double lug simple plate element tool, shown in figure 6. was manufactured by Warwick Manufacturing Group. It is a steel tool for insertion between heated press platens, using a single resin injection point between the lugs and rubber O ring seal.

To investigate the optimisation of bearing performance of the lugs, two types of test elements were designed; with attachment holes moulded in and machined after moulding. These were designed with both standard fabric lay ups and lay ups including tow arrangements. For a conventional laminated lug, the manufacture of a plain plate with a hole drilled and metal bush bonded after moulding is preferable for both manufacturing cost; since it is easier to cut a moulded plate than many layers of dry fabric, and for strength since the hole edges are more accurate. For arranged tow designs, the moulded in hole with a metal bush insert is preferable since the insert can be used to accurately locate the arranged tows.


Figure 6. RTM mould tool base with hole inserts

A series of 10mm thick lug plate mouldings were manufactured using RTM 6 resin from Hexcel Composites and two types of carbon fibre fabric: A tri-axial non-crimp fabric (NCF) from St Gobain UK of areal weight 816gsm, using Toho Tenax HTS fibre and a unidirectional tape from Hexcel Composites with a preforming binder of areal weight 268gsm using Hercules AS4 fibre. The NCF plate used 12 plies, producing a 56.7 % fibre volume fraction moulding and the UD fabric used 36 plies producing a 56.0 % fibre volume fraction moulding. The location of the fabric plies around the inserts was very time consuming and lead to a concern with resin richness (local absence of fibre) around the insert. The resin injection was carried out with 21mBar vacuum and 1.5 Bar applied pressure. For both fabrics, the complete impregnation time was 11 minutes.

Both the impregnations were very successful and the resultant mouldings had accurately moulded edges, were completely flat and had a thickness within 0.1mm of the specification. Figures 7. and 8. show an NCF preform and the resultant moulding.

Figure 7. 12 layer NCF preform before hole cutting **Figure 8. RTM moulding after edge deflashing**

5. TOW ARRANGEMENT INVESTIGATION

To investigate the influence of tow arrangement designs on bearing strength, it was decided to initially use very small, thin lugs such that many designs could be rapidly evaluated. The first set of elements used an 8 ply +- 45 degree lay up, 370 gsm areal weight 5HS satin fabric from Hexcel Composites with AS4 carbon fibres, as a baseline and lay ups with 2 arranged tow layers in various patterns, replacing 4 of the fabric layers. The carbon fibre tows have recently been developed by TohoTenax and comprise 6K HTS fibre with a coating of preforming binder of undisclosed material. The tows were placed and rigidised in position using hand manipulation and attached to the underlying preforms by fusing the binder with a hand applied soldering iron at 5mm intervals along the tow length. All of the lugs were 3.05mm thick, having 54% fibre volume fraction. Figure 9. shows the baseline lay up and the most effective arranged tow lay up.

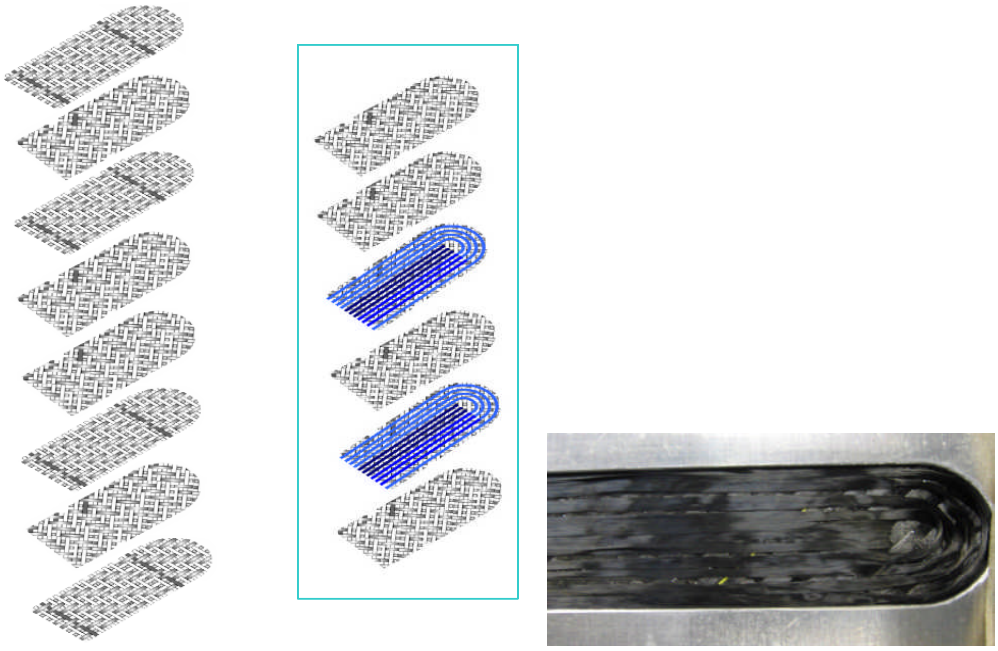

Figure 9. Baseline fabric lay up and example of arranged tow lay up.

Bearing strength testing was carried out in tension using a pinned joint between the CFC lug and two steel side plates. The testing set up is shown in figure 10.

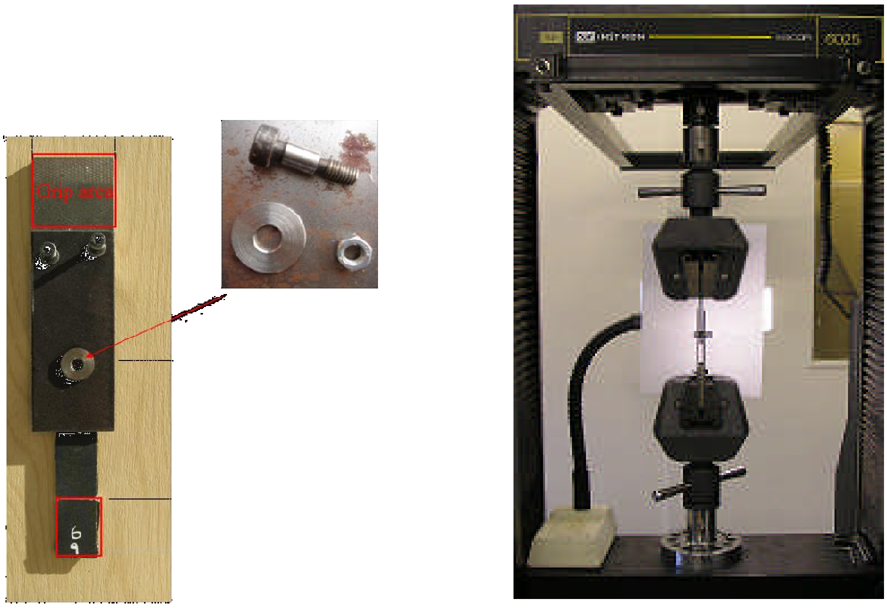

Figure 10. Tensile test equipment

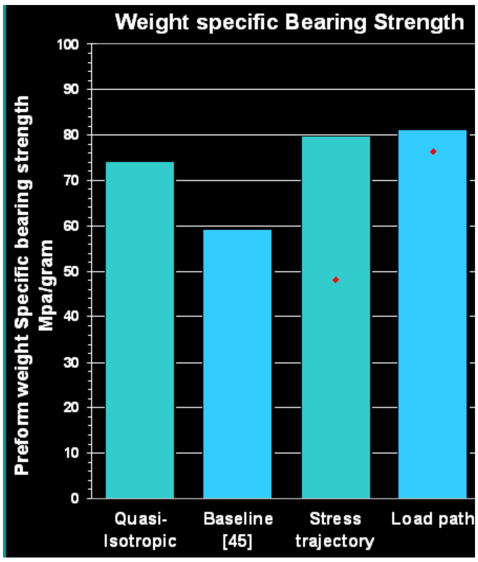

Figure 11. Weight specific bearing strength results

The initial results are shown in figure 11. The specific bearing strength was calculated by dividing the bearing strength by the weight of each preform before moulding. The value for the best arranged tow design is shown alongside both the 45 degree fabric baseline and a 0, 90, +-45 degree quasi- isotropic (QI) fabric lay up. Compared to the baseline, the best arranged tow lay up element has a specific bearing strength of 81.3 MPa/g shows a 37% increase in bearing strength and compared to the quasi-isotropic design shows an increase of 9%. This small increase compared to the fabric QI lay up indicated that more trials were required to investigate further increase of bearing strength.

Two further element sets were designed, one with a greater proportion of arranged tow layers and another with moulded in inserts. The first use six layers of arranged tows, with a ply dropping approach shown in figure 12. Since the thickness change in the region of the element including the arranged tows was so great, with a transition from 8 layers in the hole region to 2 in the base region, a ply dropping approach was taken to provide a gradual transition between the hole area and test grip area. The insert embedding investigation addressed the tow positioning in the attachment region. The first set of coupons had the tows located by eye and were positioned as accurately as possible, but not precisely around the location of the subsequently drilled hole. It is expected that the bearing strength can be significantly improved by using an embedded insert, around which the tows can be wrapped, ensuring both their accuracy of location and the absence of waviness around the hole.

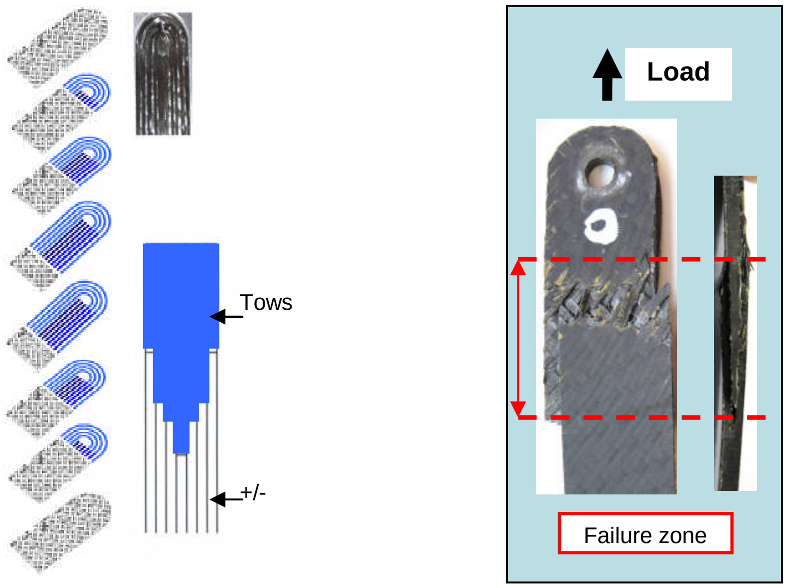

Figure 12. Arranged tow design with 6 fabric layers replaced

The specific tensile strength was 82MPa/g which is virtually identical to the best 2 layer scheme. However failure occurred by dis-bonding of the ply drop region and the bearing region was shown to be undamaged. The next challenge is how to design a sufficiently strong ply drop region and to design an optimised embedded insert approach.

8. CONCLUSIONS

The initial results show that high quality mouldings for spar components can be easily produced using high stiffness conferring carbon fibre fabrics at sufficiently high fibre volume fraction using a low pressure RTM process.

The principle of tow arrangement for attachment lugs can provide an increase in tensile bearing strength compared to conventional fabric lay ups.

The design of arranged tow lay ups is quite complex with many permutations which need further investigation before any design optimisation can be carried out. As well as the tow patterns, the blending of tows and fabrics within the lay up is complex. The provision of sufficiently high compression bearing strength may be more complex and may require a different tow lay up design approach.

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