The Manufacture of Structural Composites using Embroidery Techniques

(MASCET)

An edited version of the final project report.

Prepared on behalf of the Project Collaborators by

Ellis Developments Limited

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Summary

The objective of the project was to investigate the use of embroidery techniques for the manufacture of reinforcement preforms for composite structures produced by liquid moulding. Two embroidery techniques were assessed: the Cornely and Schiffli methods of placing fibre on an embroidery substrate material. The project developed three technical demonstrators: an automotive spacesaver wheel, demonstrating reduced weight over its steel equivalent; a generator drive end frame, demonstrating waste and assembly time reduction, plus weight saving over the conventional alloy part; and a patch reinforcement to strengthen the safety belt anchorage points on a prototype automotive floorpan.

The project assessed two different embroidery fibre placement techniques, and examined different embroidery substrate materials, fibre and yarn placement and the selection of suitable materials. The characterisation of preforms and the design of components was studied as the next stage of the manufacturing process together with an examination of the effect of fibre architecture on the structural performance.

An underlying science based project included the study of the design, processing and performance of the composites produced. The effects of variables on the processing properties of the preforms were studied and the same parameters used to examine structural properties.

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Introduction

Preform manufacture remains a major difficulty in the industrialisation of composites manufacturing techniques based upon liquid moulding. Assembly by hand of reinforcement preforms is labour intensive and, for complex parts, tends to be wasteful of raw materials. As an alternative to conventional, fabric based technologies, two existing embroidery techniques, Cornely and Schiffli, were assessed for suitability in laying down high modulus reinforcement positions and orientations necessary to tailor strength and stiffness locally, while reducing labour and waste fibres

Both processes were used for manufacture of local reinforcement for conventional preforms (patches) and for manufacture of complete, near net-shape preforms. The project addressed the design, processing and performance of composites structures using these techniques, covering the following major areas:

The effects of the embroidery process parameters on preform quality, impregnation characteristics and subsequent laminate properties. This work was done predominantly using flat plaques.
The effects of locally modified fibre architecture around point loads and cut-outs for a laminated plate subject to in-plane and out-of-plane loads. This was based on a series of flat test specimens and was later applied to automotive structures including a floor-pan and a road wheel.
The design and manufacture of net shape preforms with near-optimal fibre orientations. This work focused on an aerospace generator drive end frame.

Selection of Demonstration Components.

There were three technology demonstrators ultimately chosen for the project. The final demonstrators chosen were a Lucas drive end frame for Lucas Jaguar Space Saver Wheel and a patch reinforcement to strengthen the safety belt anchorage points in a prototype automatic floorpan.

The drive end frame selected was originally an investment casting of aluminium construction. The frame is located by peripheral slotted bolt holes. Its function is to locate an external rotating drive shaft through a bearing. Loading of the frame consists of a radial load caused by the out of balance shaft and reaction forces, and a circumferential load from the interference fit of the bearing. Finite element analysis was used to define the fibre architecture for these preforms.

This second demonstrator was a wheel hub for a high performance vehicle. Whilst in service a wheel is subjected to a range of complex interacting loads.

The critical criteria include the stiffness when subjected to out-of-plane bending, such as is experienced when cornering at high speed. Three simple load cases were identified initially: the effect of the tyre pressure; out-of-plane axle loading around the hub; and single radial compressive load. It was decided to produce the profile in two halves, each 6 mm thick with a central reinforcing boss 4.3 mm thick incorporated into the rear laminate, to be bonded together, producing a complete hub with rim.

The third demonstrator was a patch reinforcement to strengthen safety belt anchorage points in a prototype automotive floorpan. It had been found that the floor was insufficiently strong to retain fully loaded seat belt anchorages. These out-of-plane forces were similar to that the forces applied under the academic component of the project looking at out or plane forces. Fairly straightforward 3 layer patch reinforcements were designed and are described in the Appendix 7.

Establishment of Embroidery Techniques

Several machine embroidery techniques exist. The two studied were those considered to be the most appropriate for composite fibre reinforcement positioning, in that they both are able to lay fairly straight fibre configurations. The major embroidery system not used was a multi-head Lockstitch machine, which is sufficiently similar to the much higher production capability Schiffli embroidery machines used in the project.

Cornely embroidery uses a single needle head with a substrate material held in a pantograph, which is moved under computer control. One application of this technique in the garment industry is the tacking of heavy cords to the substrate by coiling the cord in a wrapping yarn, then stitching the wrapping yarn to the substrate with a chain stitch.

Schiffli embroidery uses rows of needles held on a horizontal rack, with the substrate material mounted in a vertically actuated pantograph. The primary yarn is passed through the thickness of the substrate and held in place by a second, interlocking yarn at the rear of the work.

Reinforcement Materials

The preliminary reinforcing materials selected were glass, aramid and carbon.

3.1.1 Glass

Most of the work carried out was performed on 600, 1200 and 2,400 tex assembled rovings with a saline coupling agents supplied by PPG Industries. A number of filament sizes were used within each count size, these included 13 micron filament diameter 1200 and 2,400 tex and 17 micron direct draw roving at 2,400 tex.

Because starch based sizes start to flake off and leave a fragile base the glass resin compatible finish of choice was PPG 1383 amino saline, which needs no further treatment such as heat cleaning and gave no particular processing difficulties.

3.1.2 Aramid Fibre

Both Kevlar and Twaron aramid fibres were used during the project but Kevlar was preferred because of the convenience of obtaining the fibre in a twisted form, which is much more easy to process than untwisted fibre. Aramid fibres were used as the primary fibre for the high production Schiffli process, and both Kevlar 29 and Kevlar 49 were embroidered successfully.

3.1.3 Carbon Fibre

A number of different forms of carbon fibre were used in an attempt to understand sewing difficulties that were encountered on the Schiffli process. These included both Pitch and Pan based carbon fibres in flat, twisted, high flexibility, and very fine count forms. However, the yarns tended to break as they pass through the embroidery needle eye. None of these yarns proved satisfactory. Carbon was used successfully in the Cornely process only in the later stages of the process when the principle difficulties of using stiff fibres were fully appreciated following experience gained using the cheaper glass fibres.

3.1.4 Other Sewing Yarns

There are three elements in the Cornely embroidery process. The chain stitch sewing thread is the thread that is applied to the underside of the base cloth to retain the coiling stitch to the base cloth. The coiling thread is wrapped around the reinforcing fibre and the resulting assembly is secured on the base fabric by the chain stitch. The frequency of securing the coil is set by the machine operator at the beginning of each run by a fixed gear system, but the distance between stitches on a chain sewing thread is not variable except at the design stage.

3.2 Yarn Tensions

The project defined guidance for the consideration that needs to be given during the design process to a number of features including

minimise channels forming between tows. This causes resin to race through these areas of the preform during injection, making full wet out difficult.

reducing very tight areas of tow, causing problems with resin wetting out

achieving tension equally along all the tow, to provide undistorted preforms, which will lay flat (except where a shaped preform is required).

4 Substrate Materials

There were a number of base fabric types used which served satisfactorily. These ranged from a lightweight nylon net, to a heavier woven cotton. The latter provided experience on base cloth similar to more expensive soluble acetate fabric. Base fabric also used included woven glass; stitch bonded glass mat, continuous filament random mat and glass tissue.

A large number of samples were made using stitch bonded glass structures for evaluation by the academic component of the project. These were isotropic and quasi-isotropic fabrics and provided much useful base data.

Overall, it has been appreciated during the project that for this application there is likely to be a base cloth which is suitable for each particular application as opposed to one universally useful and applicable base material. This can be chosen from a range of materials including: these discussed in Appendix 5.

Embroidery Techniques As indicated above, much ad-hoc experimentation was carried out to establish satisfactory embroidery conditions. This included understanding the requirements for stitch compensation to enhance the accuracy of fibre placement to overcome the pulling of the tow away from the position in which it was placed. This is caused by tension in the reinforcing fibre, which enlarges the stitches holding the tow to the base fabric, moving the tow away from its placement. It was found that in attaching a glass fibre tow on the Cornely machine it is relatively easy to position the tow to an accurate stitch line when the tow is in a tight bundle, if sewing thread tensions are high. However this caused problems during resin injection with the inability to penetrate the inner fibres of the tow. Further experiments were concerned with laying the glass fibre tow as relaxed and flat as possible, in order to equalise glass density over the preforms and facilitate resin penetration. This was achieved on a normal straight line, horizontal, vertical or diagonal stitching pattern. However, when stitching a tight corner or reversing sewing direction, the tow pulls away from the intended line on the return side. This can cause distortion of the desired profile.

Preform Characterisation and Design of Components Embroidery techniques were used to fabricate flat test specimens with cut-outs and these were tested in three generic loading configurations:

A narrow plate, containing a circular, central hole, under uniaxial tension (hole in a plate under tension) (Diagram 1)

A similar narrow plate loaded in tension via a pin joint (in-plane fastener pull-out) (Diagram 2)

A plate subject to out-of-plane bending via a central bolt pull-out load (out-of-plane fastener pull-out) (Diagram 3)

Diagram 1

Hole in a plate under tension

Diagram 2

In-Plane fastener pull out

Diagram 3

Out-of-Plane fastener pull-out

The materials tested included quasi-isotropic and quasi-unidirectional specimens produced using combinations of stitch bonded fabrics, embroidered fabrics, embroidered local inserts and through thickness stitching. The objective was to assess the effect of modifications to the in-plane and out-of-plane fibre architecture on resistance to concentrated loads.

Thus the potential of embroidery techniques could be examined for each particular load case with a view to applying results for more complex engineering components and structures.

The test specimens were made by hand cutting a net shaped preform, which was then vacuum, impregnated in a matched aluminium mould at room temperature. Generally, holes were produced by dry machining the moulded specimens. However, in some cases it was preferable to mould in a removable steel pin, which produced a thin resin annulus around the hole. Samples were mounted in the jaws of an Instron fitted with a longitudinal extensometer at 5 mm per minute. Load and deflection were monitored and the result processed to provide graphs of instantaneous stiffness and accumulative stiffness against longitudinal strain. In-plane fast pull-out was tested in the same way except that the lower edge of the specimen was loaded using a 10 mm diameter steel pin. Out-of-plane fastener pull out testing was carried out by supporting the specimen at a radius of 45 mm and applying vertical load to the edge of the hole by way of a 21 mm diameter pin. Deflections were monitored using the crosshead motion.

6.1 In-plane permeability

In view of the relatively large number of tests to be made during the project, a novel in-plane permeability test method was developed. This was necessary to overcome the poor reproducibility and long lead time associated with measurements of this type. The new method, which offers several important advantages, relies upon the solution of Darcy's Law for a constant flow rate, radial flow process. Pressure histories are logged along two orthogonal axes within a cavity, then plotted on a logarithmic time base, yielding a straight line graph from which the permeability tensor may be calculated. This technique may be applied using conventional laboratory bench-top equipment or in-situ using a resin metering pump. Such tests were made using a Universal testing machine to drive a variety of surrogate fluids through a free standing test rig and a reaction injection moulding machine was also used to make on-line measurements during test plaque manufacture. The latter method proved remarkably convenient for rapid characterisation of materials and was in good agreement with other test methods.

The results of the Taguchi study showed the most influential parameter to be the linear density of the reinforcement roving. Higher linear densities produced the highest axial and transverse permeabilities due to the smaller proportion of stitching yarn present. The stitching yarn reduced the porosity for a given reinforcement volume fraction, with a smaller area available for fluid flow. Surprisingly, higher stitch frequencies were also found to increase permeabilities, despite the attendant reduction in porosity. Microscopic examination showed that the coiling stitch introduced crimp channels which were found to assist flow and this effect proved to dominate over that of the porosity.

The interaction between roving filament diameter and linear density tex was the third significant effect, increasing permeability when the linear density was 2400 tex, and filament diameter was 17 microns. This suggested that the roving filament diameter ought to be 17 microns to optimise permeability, though the significance of this effect was dependent upon the linear density of the roving, i.e.

only significant when the linear density was 2400 tex. This effect was due to the packing geometry of the filaments within the reinforcement. In regions where the filaments were closely packed, the larger filaments had larger channels between them, marginally increasing the overall permeability.

In general, while the measured permeabilities of the Cornely embroidered specimens were of similar magnitude to those of commercial reinforcement fabrics, the embroidered reinforcements exhibited less anisotropy than comparable quasi-unidirectional fabrics. This was attributed to the blocking of longitudinal flow channels by the stitching yarns. Typical values for the fabrics were three to four times greater than those of the embroidered samples in the longitudinal direction, while the transverse permeabilities were similar.

6.1.1 Flow Prediction

During the resin injection process, the permeability in reinforced areas will be significantly lower than in unreinforced areas. Because of this, resin will flow round the embroidered preforms faster than through it. Where resin completely surrounds an unfilled region, trapped air will result. A study, reproduced in full in Appendix 9 describes in detail the work to develop a useful model and proposed design curves which can be used to indicate the likelihood of a dry patch occurring due to the distortion of the flow pattern caused by the reinforced area or areas having lower permeability than the rest of the component.

Effects of Fibre Architecture on Structural Performance

7.1 Design Analysis

The fibre orientations for the flat test specimens and the demonstrator components were chosen with the aid of FEA, to define elements with local axes sets so as to discretise the structure, then orienting the axes of elements with the principal orthotropic properties of the local reinforcement fibre. Obtaining a satisfactory structure therefore became an iterative process:

Step 1. Align reinforcement fibres with maximum principal stress directions determined from isotropic FEA.

Step 2. Complete orthotropic FEA using elements aligned with fibre directions, with discrete layers defined by laminate theory.

Step 3. Refine model, by realigning fibres as Step 1 and recalculating.

Strength was estimated by a factor of safety on first ply failure indicated using the Tsai-Wu failure criterion. This required some manual re-meshing every time the fibre paths were altered, although there is obviously scope for automating this potentially laborious task. The design methods, along with the embroidery methods were assessed using the generic problems and demonstrator parts described below.

7.1.1 Generic Studies

In general, the use of embroidered preform elements (patches) on the surface of conventional preforms was disappointing, producing little improvement over the base fabric case due to early delamination under loading. However, a modest improvement in performance was noted where the dominant failure mode was intra laminar shear. Cornely embroidered preforms with in-plane fibre architectures modified to surround stress concentrations generally showed an improvement over conventional preforms since the fibres could be aligned with the principal stress directions. This technique was particularly effective for in-plane fastener pull-out loadings. Through thickness stitching showed improvements in interlaminar properties, which were generally proportional to the stitch density. This suppressed delamination under out-of plane loadings. Some fibre breakage was evident at high stitch densities, which resulted in property reductions, and further work is necessary to ascertain optimal conditions in this respect.

7.1.2 Automotive Spacesaver Wheel

Spacesaver wheels are fitted as standard by an increasing number of manufacturers in order to reduce mass and costs in addition to the stated purpose of increasing luggage capacity. Despite the use of a reduced width, the pressed steel space saver supplied with vehicles such as Jaguar XJ6 remains relatively heavy at 11.2kg. The wheel represents an interesting challenge for composites manufacture and performance since, although exempt from normal braking requirements which impose a high operating temperature capability, manufacture by pressed steel or cast alloy is a well established and relatively low cost manufacturing route. The space saver was adopted as a technology demonstrator to verify the design method and to assess the potential of embroidery for reducing the labour and waste involved in manufacturing part of a relatively complex preform. The main body of the wheel was designed based on a quasi-isotropic laminate produced from zero crimp, carbon fibre fabric.

A static design based on the bending fatigue requirement resulted in a hub of simple disc form and a weight saving of 56% compared with the steel version. Cornely embroidered carbon patches were stitched (using aramid yarn) to the main body of the wheel, the patches being located on the two outer surfaces in vicinity of the hub, with the fibres aligned to inhibit crack propagation and to increase local stiffness at the highly stressed attachment points. The resulting assembly was impregnated by vacuum infusion in a single sided composite mould using a textured bagging film to form the outer face. Due to time constraints only one such component was produced in this way, although a second wheel was produced using fabric alone (i.e. without the local reinforcement) for comparison purposes. Both wheels were then passed to Ford Motor for fatigue testing under the LINK collaboration. A second design iteration was performed for which the regions of low stress in the hub were cut out to provide a spoked form, with local reinforcements surrounding the cut- outs and, as before, at the bolt holes. The projected weight saving for this version (in carbon) was 63%.

Fibre Architecture is described in Appendix 7

7.1.3 Generator drive end frame

The objectives of this prototype study (in collaboration with Lucas Applied Technology) were to reduce the waste fabric generated during preform manufacture, to reduce the preform assembly time while matching or improving the structural performance and reducing the weight compared to the conventional aluminium alloy part. The design case involved a radial stiffness of 102 MN/m and the maintenance of an interference fit for a central bearing over a range of loading conditions. The design analysis was done using PATRAN/PFEA. The first design iteration was developed using a quasi-isotropic laminate which met all of the performance requirements with a 30% weight saving and a predicted factor of safety of 2.2. A second iteration, in which the hub was designed with predominantly circumferential fibres with radially reinforced spokes and a quasi-isotropic outer flange, was analysed with a predicted safety factor of 5.9. This was based upon the same space envelope as the aluminium and quasi-isotropic versions.

The preforms for the second design iteration were embroidered using a Cornely machine with 1200g/km glass tows on 200g/m^2 plain woven substrate. Manufacture involved producing multiple layers with fibres laid according to the FEA model. The near-net shape potential of embroidery permitted the elimination of 55% waste fibre compared with conventional fabric.

7.1.4 Patch Reinforcement for Automotive Floorpan

It had been found that an automotive floorpan was insufficiently strong to retain fully loaded seatbelt anchorages. A number of glass patches were prepared and applied to the floorpan, which were subsequently found to provide satisfactory localised strength improvement.

7.2 Achieved Project Deliverables

Numerical model for impregnation of preforms, which may contain holes or inserts incorporating air entrapment.
Macroscopic and microscopic permeability models for embroidered reinforcement.
Structural design method for embroidered preforms elements.
Demonstration of the potential for embroidery as a manufacturing process for preform element using the demonstrator components.
Manufacturing method for embroidered reinforcement demonstrating improved structural performances and increase material efficiency compared with conventional fabrication techniques.
Determination of process sensitivity to geometric tolerances.
Technology transfer between textile and engineering based organisation.
Reduction in preforms assembly times and costs.
Improvements in the component performance.

Dissemination

During the lifetime of the project there were quarterly meetings of the project members when progress was reported.

Dissemination is now a continuous, ongoing process, because the technique has been demonstrated by the project to be able to provide a potentially valuable tool for manufacturing fibre architecture that cannot be achieved by other means, and hence can solve difficult design problems.

Interest has been raised through a number of routes, which involve the following items listed.

7.4 Journal Papers

C.D. Rudd, L.J. Bulmer, D. J. Morris, and K. N. Kendall "Compaction and in-plane permeability characteristics of quasi unidirectional and continuous filament random reinforcements", Materials Science and Technology, Vol. 12, No 5, P436-444, May 1996

C D Rudd, N A Warrior and J Ellis "Embroidered Reinforcements for Structural Composites" Materials Technology Vol. 12 No1 Jan/Feb 1997

7.5 Published Conference Papers

C.D. Rudd, J. P Chick D. J. Morris and N. A. Warrior, In-plane Permeability Characterisation of Mats and Fabrics Using SRIM. Proceedings ICCM-10, Whistler, BC (1995), Vol. 3, P181-188, Woodhead Publishing.

C.D. Rudd, D. J. Morris, J. P. Chick and N. A. Warrior, Material Characterisation for SRIM, Proceedings ICAC-95, Institute of Materials, Nottingham, UK (1995), Vol. 1, P21 1-218

D. J. Morris, C.D. Rudd, S. P. Gardner and N. A. Warrior, "The Effects of Embroidery Parameters upon processing and Mechanical Properties of Comely Embroidered Quasi-Unidirectional Reinforcement." Proceedings FPCM-96, Aberystwyth UK (1996)

7.6 Conference Presentations

D. J. Morris "In-plane permeability measurement techniques", Symposium on Resin Transfer Moulding, University of Nottingham, March 15 1996.

N A Warrior "Performance enhancement in composite laminates using embroidered preforms" ICAC-95, Institute of Materials, Nottingham, UK (6-7 Sept. 1995)

J Ellis and N A Warrior "Design and Manufacture of Stressed Components using Embroidery" LINK Structural Composites Open Day, University of Nottingham, 8 July 1996

N A Warrior and J Ellis " Manufacture of Structural Components using Embroidery Techniques" LINK Structural Composites Awareness Workshop, DRA Farnborough, 23 Oct. 1996

D J Morris "Processing and Performance of Structural Composites using Embroidery Techniques" INTERPLAS Technical Sessions - 13 Nov. 1996

7.7 In Preparation

S. P. Gardner "The use of embroidery techniques in structural composites" Ph.D. Thesis 1997 The University of Nottingham

D. J. Morris "The effects of textile variables on the processing properties of reinforcement fabrics" Ph.D. Thesis 1997 The University of Nottingham

S. P. Gardner, D. J. Morris, N. A. Warrior and C.D. Rudd "Embroidery techniques applied to a composite plate with a central hole, under uniaxial tension"

S. P. Gardner, D. J. Morris, N. A. Warrior and C.D. Rudd "Embroidery techniques applied to an hole in a composite plate under in-plane fastener pull-out loading"

7.8 Technical Reports

Thirteen Progress Reports issued to LINK partners at 3 monthly intervals during project life.

7.9 Patents

Full discussions with patent agents from two consortium members lead to the decision that it would be inappropriate to apply for any patent cover for techniques developed in the project. A consensus was reached that any IPR should be related to specific novel solutions related to actual applications of the technique.

Exploitation 8.1 Achievements and Further Plans
There has, as yet, been no commercial application of embroidery to composites. The techniques would probably not have justified LINK support had that been the expectation. However, the foundation work for this new technology has been carried out and there is ongoing consideration being given towards development of new commercial applications.
A MedLINK proposal was made for the application of embroidery to surgical implants, notably for the repair of abdominal aortic aneurysms (weakness in the main aorta). This was accepted, and a £315,000 project began in May 1996. Ford Motor Company have ongoing interests in the application of the technique and presentation have been made to a number of interested commercial

organisations as well as the more general presentations outlined above. The team spirit developed in the project is set to continue, and commercial development will arise from the collaborative team.
An application has been made by Teritex under the EC Craft Scheme for a co-operative study in co-operation with Leveaux SA of France on the subject of through stitching of embroidered composite preforms. This application has been approved.

Recommendations for Further Research

Optimise stitch density for Interlaminar strength and toughness.

Develop cutting head for Cornely Machine.

10. Conclusions

The initial feasibility studies on manufacturing capabilities demonstrated the practicality of embroidering high modulus fibres for low waste production of preforms for liquid composite moulding. The aggressive nature of the stitching process limits the choice of substrate, reinforcement and stitching materials, though suitable materials were identified and utilised successfully. Minimising the volume of stitching material within the preform improved permeability and compliance, which in turn led to improved structural performance under tensile loading.

Finite Element analysis proved to be a useful design tool for investigating the performance of modified fibre architectures, though the iterative process of optimising fibre architecture was time consuming. Experimental results demonstrated that structural performance under in-plane geometric stress conditions and in- and out-of-plane contact situations can be improved by the correct application of embroidery techniques. Manufacture of complex 2-dimensional preforms using embroidery can substantially reduce waste, and also reduce the assembly time of multi-layer preforms over using conventional fabrics.

Appendix 1

11.1 Collaborators

University of Nottingham, Department of Mechanical Engineering

Akzo Fibres Limited, Leicester (now Tenax fibres)

Cray Valley Limited, Yorkshire

Crescent Consultant Limited, Nottingham (SME)

Ellis Developments Limited, Nottingham (SME)

Ford Motor Company, Essex

Hewetson Leveaux Limited, Buckinghamshire (SME)

Lucas Applied Technology Limited, West Midlands

Geoffrey E Macpherson Limited, Nottingham

PPG Industries UK Limited, Lancashire

Vidhani Brothers Limited, (T/A Teritex) Nottinghamshire (SME)

Advanced Structural Technology Limited withdrew from the project as soon as it started. It was hoped to replace them by Lotus Cars who unfortunately failed to sign the final agreement to join the project. The work proposed by them was shared and performed by other collaborators.

Appendix 2

Original Work Plan (as Revised)

1. Identification of Demonstration Components

2. Establish Embroidery Techniques

Yarns

Yarn Paths

Yarn Tension

Sewing head

Types of needle

3. Substrate Development

4. Control of Movements

Design/CAD

Algorithms

5. Sewability of Substrates

Presentation

Reinforcement laying

Holding reinforcement

6. Preform Characterisation and Design of Component

Structural Analysis

Load bearing and dissipation

7. Resin Impregnation

Flow modelling

Prototyping

Permeability Studies

8. Component Evaluation

Non-Destructive Evaluation

Microscopy

Mechanical testing

Environment testing

Technique Validation

Application to General Problems

9. Design for Manufacture

Strategy

Technical Manuals

Demonstration components

Cost evaluation

Appendix 3

13.1 PROJECT OBJECTIVES

To identify the most appropriate and effective technique of attachment of a range of reinforcing fibres to the base cloth

to optimise the preparation of fibres for embroidering, and their presentation to the sewing head

to investigate the interaction between the base cloth and the embroidery yarns

to optimise the preform stability for mechanical handling before impregnation and during the impregnation process itself

to optimise base cloth properties

to develop an understanding of the effects of different base cloth removal techniques to investigate a range of stitching structures

to minimise any unwanted fibre movement

to optimise resin introduction and flow paths into complex shapes

to control uniformity of resin/fibre proportions

All the project objectives have been met, with the exception of the full anticipated component evaluation. It became clear during the later part of the project that the properties that could be enhanced by embroidery techniques were such that a considerable amount of further work was needed to develop and evaluate component properties, in particular, through thickness properties such as impact tolerance to identify the most appropriate and effective technique of attachment of a range of reinforcing fibres to the base cloth.

Appendix 4

14.1 Comparison between Cornely and Schiffli Embroidery Techniques

The Cornely system results in the fibre tow being held onto the substrate with a chain stitch to create a net shape preform whereas the Schiffli machine uses direct stitching of high strength, high stiff fibre to the reinforcement fabric. The Cornely system uses high modulus fibres on the surface, which increases bending stiffness and increases local volume fraction, thus increasing the structural properties. However, modulus differences lead to delamination and local volume fraction increases tend to reduce permeability. Schiffli embroidery allows the potential for stitching which improves the intra-inter-laminar properties due to hybrid reinforcement increasing the X Y and Z properties. However the stitching through process tends to damage the substrate, and through - thickness stitches are rarely taught. Although this through stitching may reduce the old strength, the energy absorption of the composite increase. The use of through stitching tends to increase manufacturing flexibility through joining by stitching.

14.2 Cornely Advantages and Disadvantages

Using high modulus fibres on the surface increases bending stiffness increases local volume fraction - increasing structural properties

modulus difference leads to delamination

increases local volume fraction - reducing permeability

14.3 Schiffli Advantages and Disadvantages

stitching improves intra- and inter- laminar properties due to hybrid reinforcement (increase in x, y and Z properties) stitch through process damages substrate moulded-in aramid provides stress concentrations

through-thickness stitches are rarely taut

14.4 Effect of Cornely Stitching-on

stiffness is increased

strength is unchanged

energy absorption is increased

14.5 Effect of Schiffli Through Stitching - Aramid

ultimate strength is reduced

energy absorption is increased

14.6 Cornely

A fibre tow is held onto a substrate with a chain stitch to create a net shaped preform

14.7 Schiffli

Is direct stitching of high strength, high stiffness fibres into the reinforcement fabric

14.8 Embroidery Benefits

Increased strength/stiffness

Increased energy absorption

Increased manufacturing flexibility through joining by stitching

15. Appendix 5

15.1 Factors to be considered in the Textile Design Phase

Yarn Orientation. A balance must be maintained between maximised strength of the component and minimised component weight.
The accuracy of the placement of the fibre can be achieved by increasing the number and the tension of holding stitches but this must be balanced against the loss of preform permeability if these are too high.
The shape of the roving as it is laid on the base material can be altered by changing the shape of the feeder. This requires optimisation to obtain the ideal yarn packing and the permeability of the roving fibre bundle.
A higher yarn count will be reflected by reduced flexibility and therefore the accuracy of fibre positioning will be reduced.
Some components require non structural areas where fibre is placed simply to provide a filler. Such non structural areas require identification at an early stage of the design process.
Consideration must be given to the number of layers that can be achieved in one preform element and preferably the maximum thickness obtainable will be built up within one sewing operation.
Yarn twists affects processability and positioning. Consideration must be given to the effect of twist on precise positioning. The use of a high twist yarn will improve positioning, but reduce the permeability of the preform.
If different layers of preforms can be constructed simultaneously, consideration must be given to the different yarn orientations required to give the desired combination of directional properties.
The effect of substrates on sewability, permeability and component performance needs to be considered when selecting the substrate. The exact choice of substrate clearly has influence on the fibre pattern chosen because of the contribution of the substrate to the structural performance.
The potential for blending different material in areas of the component to locally modify, properties must be considered. It is feasible to change the reinforcing fibre during a single embroidery process, for example a
Change to Aramid from glass or carbon is possible, and different accounts of the same fibre maybe used automatically.
It is possible to introduce deliberate preform distortion to provide for example for dome or cup shapes through unequal tension being applied to the two sides. This provides a method of making curved preforms.
Changes in yarn directions during embroidery results in design distortion. When the yarn turn around is reached, yarn is pulled back by tension effects altering
The intended yarn position. Compensation must be introduced to eliminate these effects.

Yarn paths chosen are component specific, and developed on the basis of the identified areas of stress concentration. Such concentrations maybe identified by finite element stress analysis, or simply empirically, depending upon the critically of the components. Examples of yarn paths are shown in the following diagrams - Figure 4 o figure 8

Figure 4

circumferential yarn path on part, deviating locally to radial arrangement

around bolt hole

Figure 5

Radial yarn path on part, deviating locally to circumferential arrangement

around bolt holes.

Figure 6

5 hole circular part

Figure 6 illustrates circumferential yarn placement with even density of yarn packing and no overlaps. In this instance the yarn between the bolt holes butts up to the hole with slight overlap for later trimming or machining.

5 holes circular part illustrating sets of parallel fibres curving smoothly around the part of the hole nearest the part centre.

In figure 7, the sharp yarn direction changes are placed in a non-critical load area where they cannot contribute to part failure. There is uniform yarn packing and no yarn overlapping.

Figure 8

Sets of parallel fibres deviating around a central hole.

Figure 8 shows the arrangement used in the demonstration of component the seal belt anchorage. The same yarn path rotated three times through 60o produces a washer resistant to in and out of plane loading. This complex component has been successfully embroidered into one preform of three layers.

16. Appendix 6

16.1 SUMMARY OF A REPORT ON A GENERIC STUDY OF FLOW AROUND CIRCULAR REINFORCING PATCHES IN RTM

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When designing RTM components with circular reinforcing patches such as those proposed in the MASCET project, the design curves shown in the report can be used to indicate the likelihood of a dry patch occurring due to the distortion of the flow pattern caused by the reinforced area or areas having lower permeability than the rest of the component. The curves apply to components with isolated patches and to components with a row of patches parallel to the flow front. The reinforcing patches must be continuous, circular and uniform, and the permeability of reinforced and unreinforced areas must be isotropic. For other cases, the design curves may give an indication of the suitability of the design, and whether it is necessary to carry out a detailed study of the flow in that component.