AUTOMATED CONSOLIDATION DURING THE MANUFACTURE OF COMPOSITE MATERIAL BASED COMPONENTS

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SUMMARY: An automated system was developed for the design and manufacture of fibre reinforced plastic structures to substitute the high cost of labour in the current manual lay-up processes. This paper discusses the consolidation a proposed servo-controlled air-jet campaction system. The air-jet was designed and manufactured for use as a robot end-effector which provides an additional degree of freedom in the automated manufacturing of composite components made from prepreg and dry fabrics. This air-jet unit is computer controlled for precise vectorial and spatial positioning with respect to the tool used in the manufacture of a composite component. The focus of this paper is in the manual experimentation, which essentially simulates the proposed servo-controlled air-jet compaction system. The results, in terms of consolidation consistency, are presented with and without a process-aiding tangential force.

KEYWORDS: Automated manufacture, fibre reinforced plastic composites, robotic end-effector, ply consolidation, control systems, spatial position.

INTRODUCTION

The use of fibre reinforced plastic structure has been limited by high manufacturing cost due to their labour intensive manual lay-up processes, which are inherently costly, and which attract additional costs because of the extensive inspection required for quality control. These issues have been addressed by developing automated flexible manufacturing systems for advanced composite structures. A number of such systems, reported in the open literature, are presently in various stages of development [1]-[5]. A major difficulty identified in these programs is associated with the consolidation of prepregs and dry fabric tows on the tool, particularly for components with double curvature or curvature about two axes.

A larger research program has carried out to develop a low cost system for the automated manufacture of high quality composite components from prepreg and dry fabric [6]. This automated lay-up system uses a concurrent design-for-manufacture philosophy in order to simplify the overall process so as to make it more amenable to automated manufacture. The basis system involves generating a draping finite element(FE) model using an FE computer package. The lay-up in the FE model is defined using a protocol in which the the draping sequence of the ply is defined as part of the design process. The information relating to draping simulation is used to control the automation [6]. The system was designed for cost-effective manufacturing by maximising flexibility, minimising human intervention during manufacture and maximising exploitation of a unified computer database.

This curent research has focused on the end-effector's development, which has been shown to be a critical part in developing such an automated system in past attempted research. An air-jet compactor driven by a servomotor has been developed to use compressed air to consolidate prepreg and tacky dry fabric plies. The orientation of the nozzle at the end of the compactor enables the unit to work on most surfaces used in creating composite parts, including those with complex curvatures. Tests performed at RMIT confirmed that the air-jet provided sufficient compaction force without tearing fibres from carbon prepreg fabrics and dry fabrics.

In comparison to rollers, the most common lay-up tool, compressed air is an alternative method for draping composite sheet onto tools. Combined with manual tools, compressed air is particularly useful in draping materials into difficult areas. Heat is normally applied together with compressed air, which can help soften the prepreg to provide the required flexibility to make draping easier. Although compressed air is best suited to parts with complex curvature, it can be used on flat or slightly curved moulds by altering shape of the nozzle.

Before the design of the air-jet, an investigation was carried out to establish whether a force normal to the tool surface could implement controlled shear draping in a single fabric ply. From this result, the air-jet method was employed for laying up and consolidating prepreg composite sheets onto a mould.

A SINGLE NORMAL FORCE FOR PLY LAY-UP INVESTIGATION

A single normal force was used in an attempt to form composite plies onto a hemispherical mould tool. This test was used to prove whether a single normal force is sufficient to lay-up a composite ply into the desirable shear-draping configuration.

Test Description

The single normal force was applied using a smooth plastic applicator, of 6mm in diameter, held by a hand vertically to the tool surface. (Ref. Fig. 1). All zero strain lines were fixed onto the tool by sticky tape to ensure these edges remain fixed. (Ref. Fig. 1 & Fig. 2). The hand application resulted in variable applied forces normal to the surface. The draping path followed is schematically described in Fig. 2. From the draping start point (DSP), the applicator pushed the fabric onto the tool in a number of positions along an arc between the zero strain lines. (Ref. Fig. 2). After each successive applicator position, the fabric was allowed to relax in order to eliminate localised wrinkling.

The distance between successive applicator position was varied from 25mm to 10mm. The composite plies used were dry glass fabric and carbon fabric, and prepreg carbon fabric. During the test, these sheets were cut into 200x200mm square pieces. Grid lines were marked onto the top side of each fabric to highlight 20x20mm or 15x15mm squares. This is required to show the shearing effects after consolidation. The mould was a 200mm-diameter polished hemispherical mould made from hard-wood. Super 77 spray adhesive was applied to the mould before the experiment.

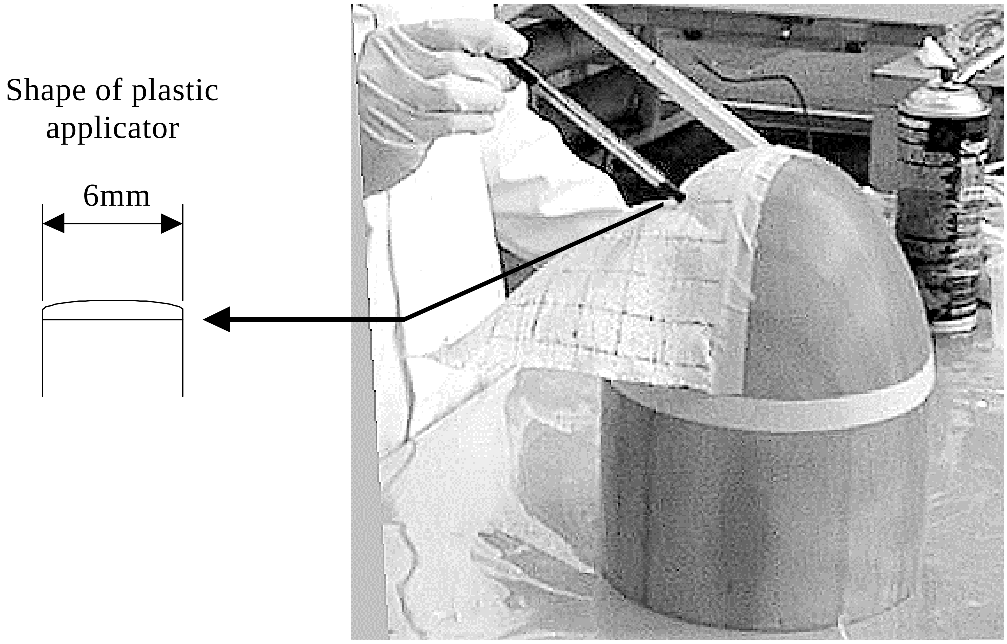

Fig. 1: Normal Force Set-Up

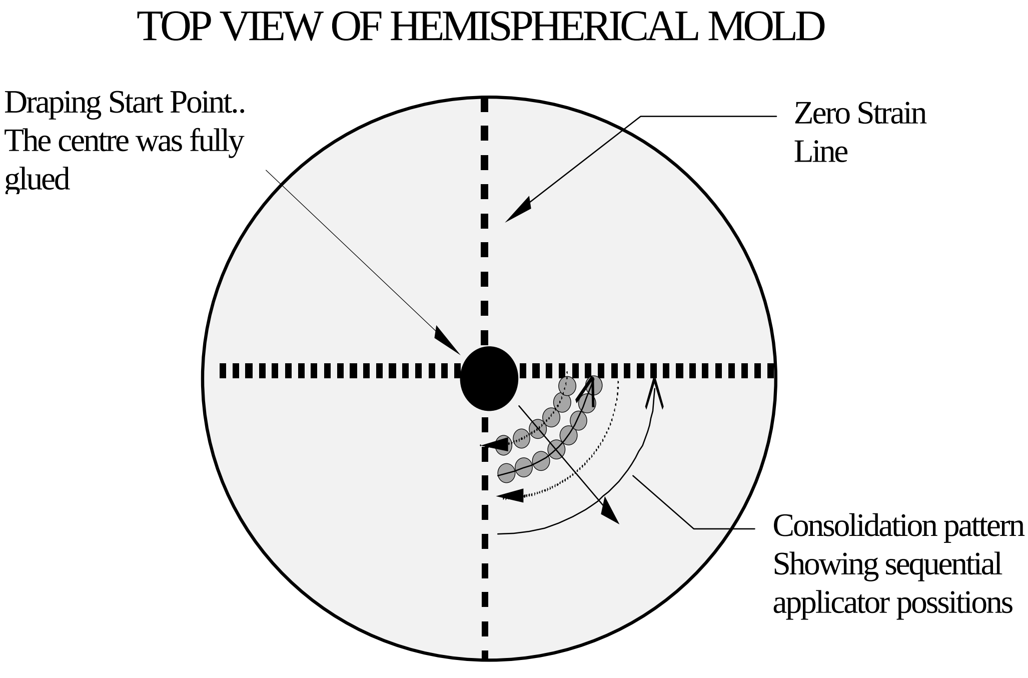

Fig. 2: Draping Strategy

Results & Analysis

The result for dry glass fabric at 25mm draping steps is shown in Fig. 3 and Fig. 4 at 30% and 80% coverage respectively. The grid lines were at 25mm squares Fig. 3 shows that at 30% coverage, the glass fabric fitted onto the tool surface with slight shearing. After 80% coverage however, the shearing was clearly noticed.

When draping steps are reduced to 15mm steps, but following the same draping pattern, a great improvement in the consistency of the final consolidated form was achieved. (Fig. 5 and Fig. 6). There was however a large wrinkle in the lower region (Fig. 6), but this was in the area to be trimmed after cure. A similar result was obtained using the carbon fabric.

Fig. 7 and Fig. 8 shows an experiment where an artificial biased tension force of 1.64N was applied when draping dry carbon fabric at 25mm steps. While this shear force was applied, the draping pattern was initiated as described previously. The results suggested that the addition of a small biased tension force into the consolidation stage is very helpful in increasing the draping speed.

The application of heat was also investigated. Carbon prepreg fabric was draped in steps of 25mm without the shearing force, at up to 60-80°C. The results are shown in Fig. 9 and Fig. 10. The use of heat alone can help draping since no wrinkles were observed.

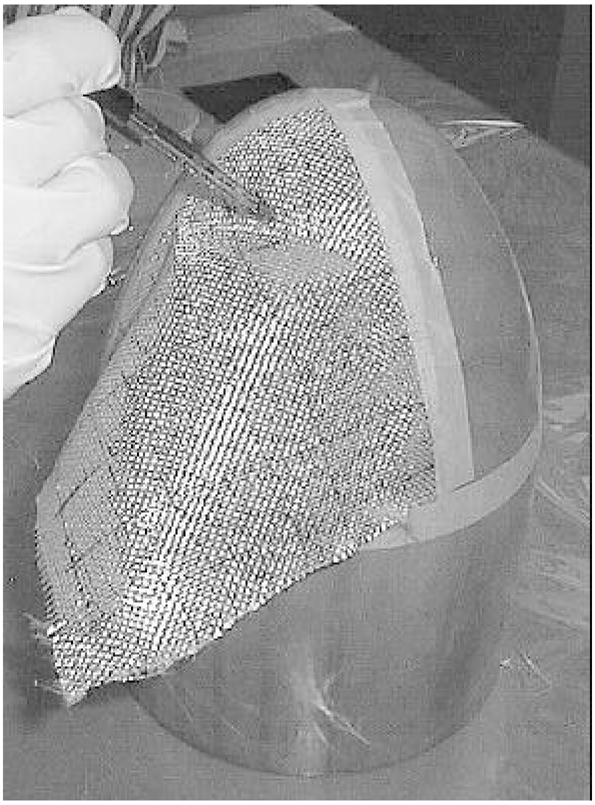

Fig. 3: Glass Fabric, 30% Consolidated ($25mm^2$ Grids)

Fig. 4: Glass Fabric crimped at approx. 80% Consolidation ($25mm^2$ Grids)

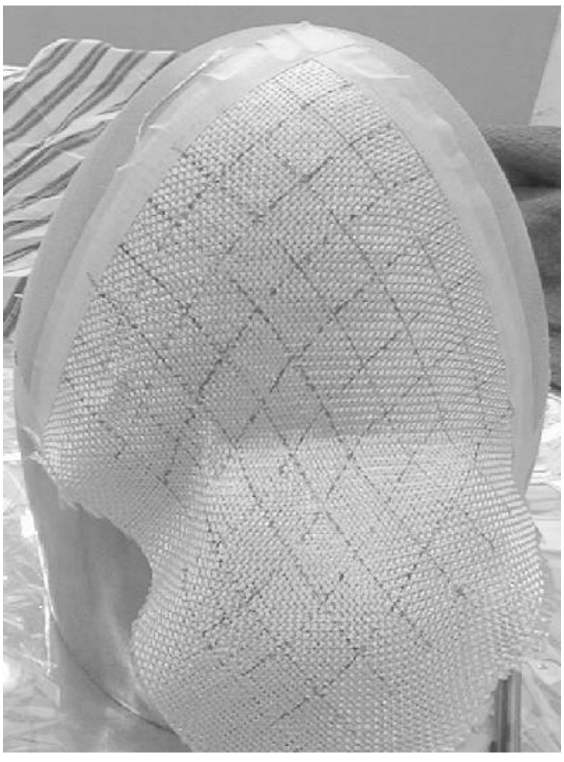

Fig. 5: Glass Fabric at 80% Consolidation. No wrinles present. ($15mm^2$ Grids)

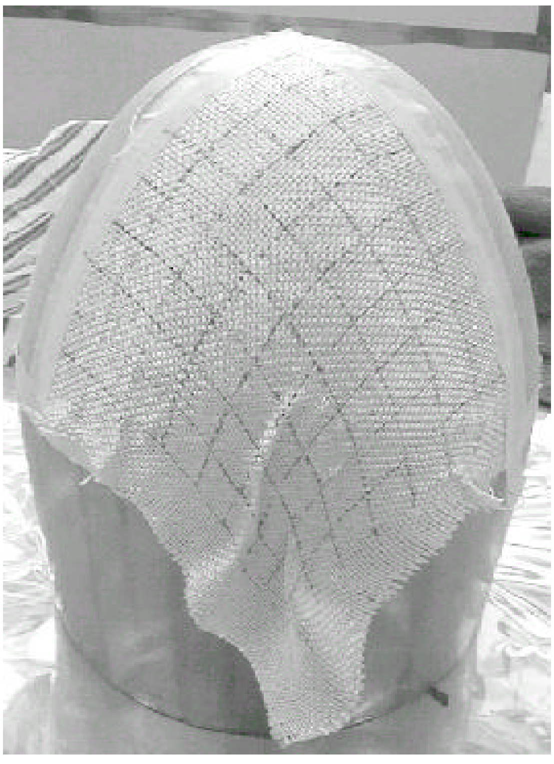

Fig. 6: Glass Fabric at 100% Consolidation. Note the wrinkle. ($15mm^2$ Grids)

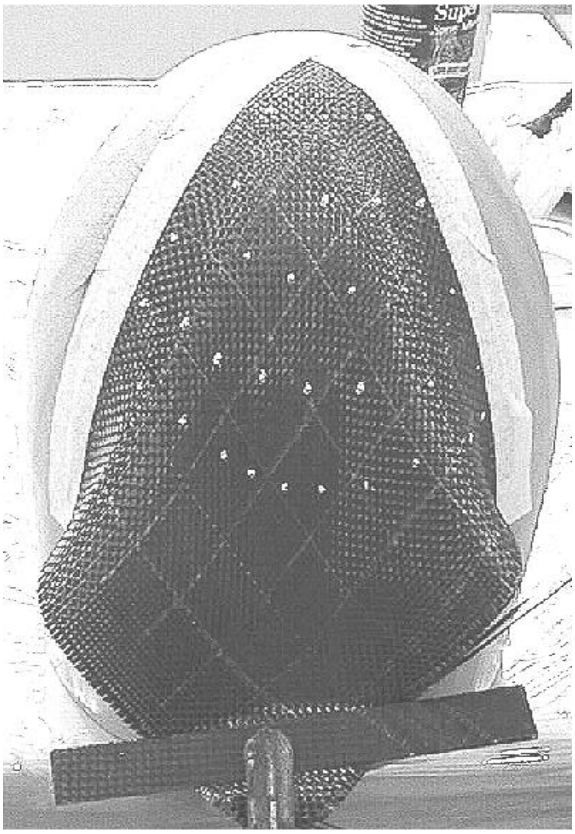

Fig. 7: A clamp is used to give 1.64N in shear force. 0%Consolidated. (25mm^2 Grids).

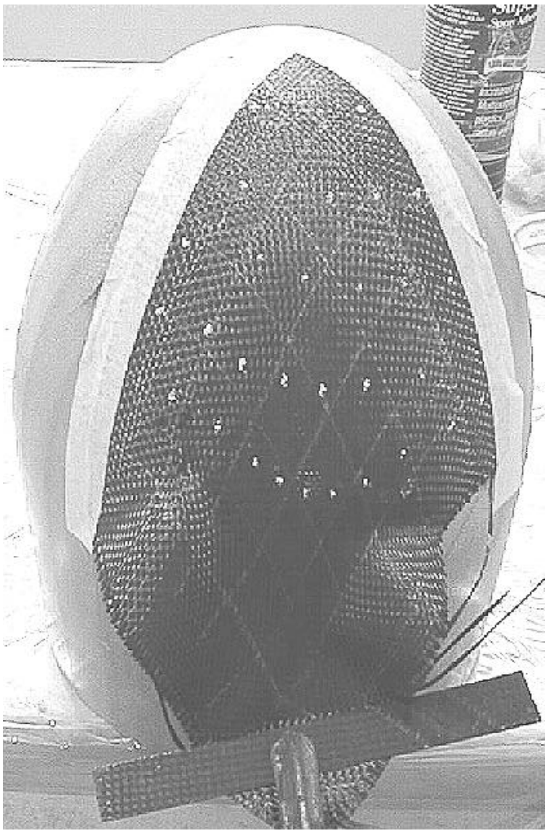

Fig. 8: 100% Consolidated. No wrinkles present. (25mm^2 Grids).

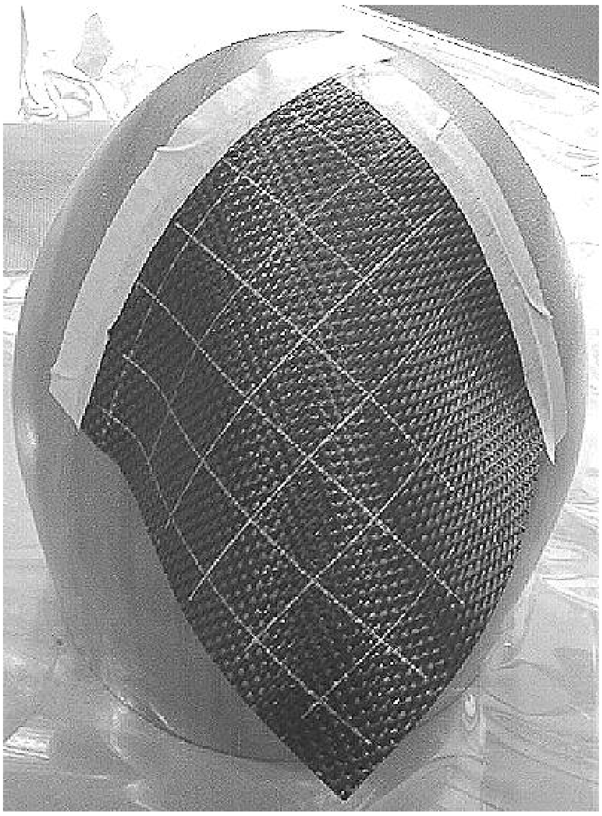

Fig. 9: Carbon Prepreg Fabric Before Consolidation. (25mm^2 Grids).

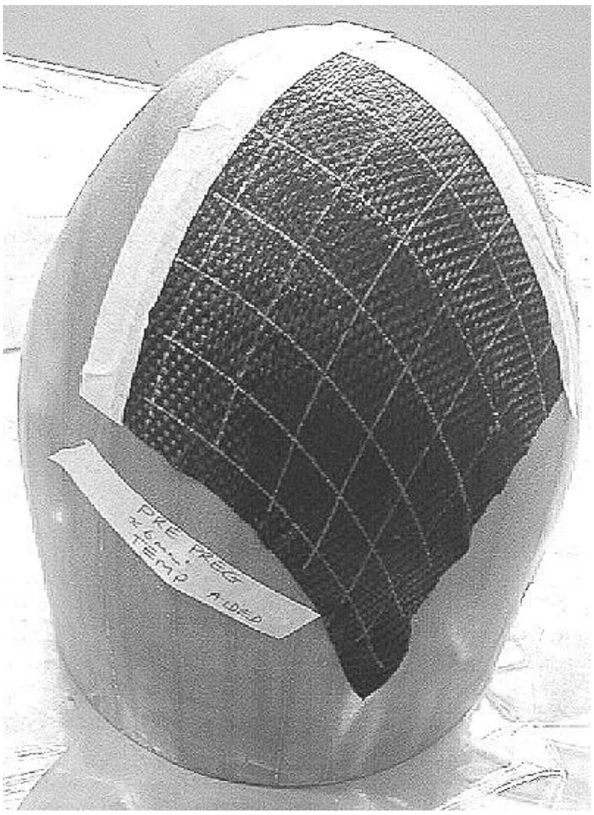

Fig. 10: Carbon prepreg fabric consolidated at about 80°C. No wrinkles present. (25mm^2 Grids).

CONCLUSION

Tests results showed that a single normal force alone can be used to drape composite fabrics onto a hemispherical mould. Hence, double curvature tools can be consolidated with the application of a single normal force. Smaller draping steps may be necessary for effective consolidation especially for parts with complex shapes and bends. This was demonstrated when reducing draping steps from 25mm to 15mm resulted in improved consolidation consistency. Although it was demonstrated that a normal force was sufficient to form the fabric, the addition of a small in-plane bias tension force makes the procedure much easier.

The feature of heating may be a topic for further investigation as this is expected to affect the tackiness of the prepreg fabric and hence leading to handling problems.

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