Title: **Feasibility of Low Cost Fabrication of Lightweight, Protective Structures using Thermoplastic Matrix Composites**

2nd Interim Report

by

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13. ABSTRACT *(Maximum 200 Words)*
The report describes the continuing investigation into processing and testing of thermoplastic composite structures for ballistic production. A review of the progress so far details the process being used and the development of baseline molding conditions. Some testing has also been carried out including burn-off, microscopy and impact tests; results are mentioned where appropriate. Some unforeseen problems delayed the planned molding program, but a temperature-time processing window for each thermoplastic will soon be established. Production of test panels can then begin along with suitable mechanical and impact testing.

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Feasibility of Low Cost Fabrication of Lightweight, Protective Structures using Thermoplastic Matrix Composites

Progress at 15 March 2001

Molding has begun and several panels have been produced using both E glass and S2 glass with LDPE and polypropylene film; the results in most cases have proved to be promising. Burn-off tests and microscopy have been carried out and show that panels with a fiber volume fraction of up to 61.8% are possible while maintaining good reinforcement wet out. Unfortunately progress has been hindered slightly due to some unforeseen delays with tool modification and to date work has concentrated on the development of processing conditions. Some impact testing has been carried out on these preliminary panels although this, along with other mechanical testing, will become more of a focus once the production process has been refined.

Initial Processing and the Refinement of Baseline Molding Conditions

The majority of the panels produced at this time have been E glass/LDPE composite as the low cost of these materials minimizes the expense of establishing process conditions. S2 glass has also been used for a number of panels because it is actually a more tightly woven fabric and there was concern about the lower permeability. Initial results have been promising but to date the consolidation of the panels has been accomplished using a tool face pressure of 37 bar (536 psi). This was chosen arbitrarily as the highest achievable pressure and although the overall scope of the investigation is towards low cost molding it should be remembered that film stacking is simply a vehicle to allow the production and testing of thermoplastic matrix panels where commingled and reactive formulations are currently unavailable.

The main problem with an isothermal process of this type is the time taken to produce each panel. The tool being used is not equipped with any cooling facilities and while the time to heat up is relatively short it cools at a rate lower than 1°C min^{-1}. Heating above the melting point can reduce the melt viscosity of the polymer but in the case of LDPE heated to 170°C it takes over one hour to cool to a manageable temperature. The length of time at high temperature raises the problem of degradation, both of the polymer and, in the case of composites using aramid, the reinforcement itself. For these reasons a modification has been made and the process now being used is non-isothermal. The heaters are set at the required temperature and the charge is assembled between a pair of removable aluminum plates that can then be transferred to the press. It takes less than one minute for the charge to reach temperature and it can be removed easily once impregnated. Although it is still above its melting point, the aluminum plates prevent deformation while allowing a vastly increased cooling rate and a shorter cycle time. It maybe necessary to carry out secondary consolidation in another press to maintain the integrity of the panel but this is being investigated along with the establishment of a suitable temperature-time window for each of the thermoplastics in the study.

According to the literature [1] film stacking can be used to produce panels with a fiber content of between 70 and 80%, by mass. A simple equation can be used to work out the required ratio of film to fabric layers but in some cases this is less than 1:1. As ply ratio is reduced a longer cycle time is necessary to force the high viscosity polymer through several layers of reinforcement. A ratio of 1:2 has been used for some panels using both E glass and S2 glass and so far this seems to have been successful although there is some evidence of voids.

Testing

Although V_f can be calculated as mentioned above, burn off tests have been carried out on the preliminary panels to establish the actual percentage of reinforcement in the panels being produced. Mass fraction ranged from 66.7 to 84.0%, which gives V_f between 49.1 and 61.8% depending on the type of reinforcement and the ply ratio.

Samples from each panel have been cast in resin and examined under a microscope to ascertain the extent to which the material has consolidated. No voids have been found so far in the panels with ply ratio of 1:1 and only a few with the 1:2 ratio (figures 1 and 2). This suggests that film stacking is a suitable process for the production of thermoplastic matrix composite panels for the purpose of this investigation.

Some drop tower testing has also been carried out on the preliminary panels using the 7.62 mm AP and FSP impactors. Results have yet to be properly analyzed but more focus will be placed on this type of testing once molding of the matrix has begun. Testing was also carried out on equivalent dry lay-ups of reinforcement. There is, however, a limited clamping force on the drop tower and during penetration fibers were pulled out of position as opposed to shearing or failing in tension, which is the normal case during a ballistic impact. Further investigation is planed and a rig is being made that will secure the fabric more efficiently and allow comparable results to be produced.

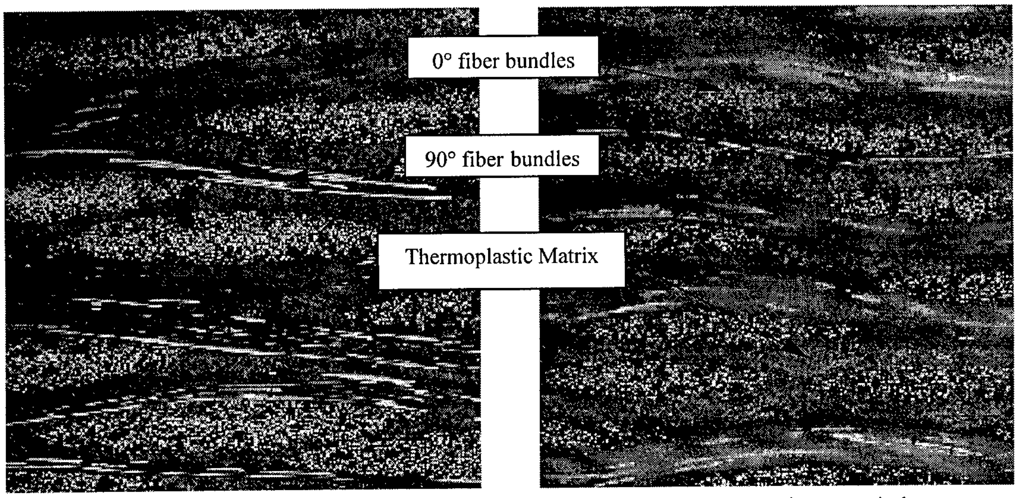

Figure 1 10x magnification of samples 0002-01 and 0005-01; E and S2 glass composites respectively containing 15 layers of reinforcement and 16 layers of LDPE film

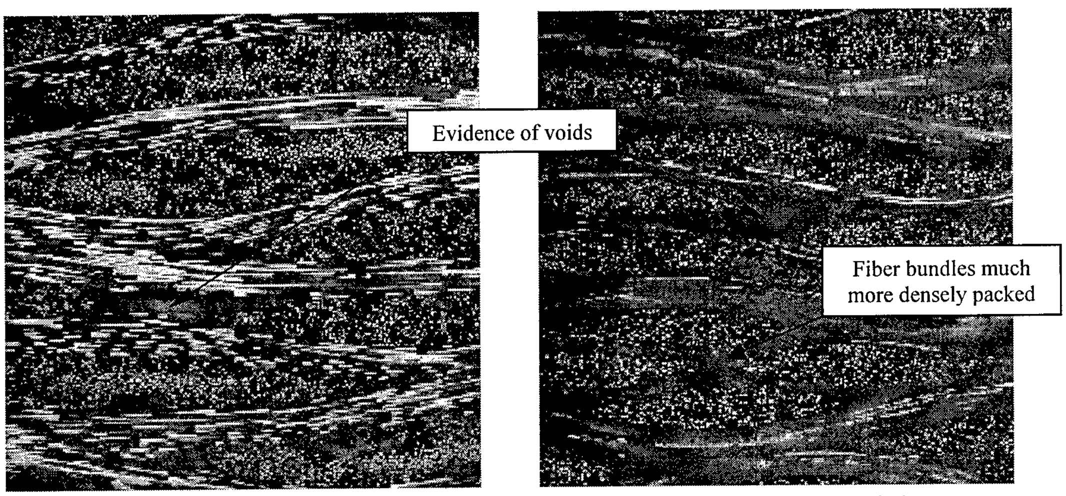

Figure 1 10x magnification of samples 0006-01 and 0008-01; E and S2 glass composites respectively containing 16 layers of reinforcement and 8 layers of LDPE film

Future Work Program

Processing Matrix

It has so far been proved that film stacking can be used to produce thermoplastic matrix composites. A further short period of molding trials is, however, considered necessary to establish a satisfactory temperature-time window for each thermoplastic. This needs to be done as quickly as possible and once it has taken place molding of the planned matrix will commence using S2 glass and aramid reinforcement. Further investigation and optimization of precise molding parameters and processing techniques can then be carried out for the most promising materials.

Testing

Burn off and microscopy will continue to be carried out during the establishment of process conditions and to ensure the quality of the panels once the molding of planned matrix begins. Drop tower testing will also continue and it is hoped that some samples of current ballistic materials can be acquired to allow accurate comparative analysis. The rig for dry lay ups, which is being manufactured, may also give some useful results as well as allowing quasi static penetration tests using the Universal testing machine. Mechanical tests will also begin once the process parameters have been refined and suitable panels are being produced.

Although the non-isothermal process currently being used has reduced the cycle time there is still the possibility of high temperature degradation of the plastic taking place. This has previously been investigated at the University as part of work done on glass reinforced polypropylene [3]. The School recently acquired a Perkin Elmer Pyris 1 Differential Scanning Calorimeter (DSC) machine and further experimentation of this type is planned over the next period.

Administrative Actions

No significant administrative actions have taken place over period 15 December 2000 – 15 March 2001.

Other Relevant Information

The commercial test range previously mentioned has proved to be more expensive than initially thought and has been discounted. The Impact Research Center at the University of Liverpool, however, has the facilities to carry out high velocity dynamic testing using various rigs and guns. It is possible that this facility may be used for a minimal charge and it is currently under negotiation.

Trials of injection processing using a reactive formulation of PA 12 at EPFL (Lausanne, Ch) do not now appear to be possible. EMS does, however, also have rights to the process and have been contacted about trials using aramid reinforcement.

References

1 **Song J.W** 1994 'Thermoplastic Composites for Ballistic Applications' *International SAMPE Technical Conference, October 17-20 1994*

2 **Wang B. and Chou S.M.** 1997 'The behavior of laminated composite plates as armor' *Journal of Materials Processing Technology 68 279-287*

3 **Wakeman M.** 1997 'Non-isothermal Compression Moulding of Glass Fibre Reinforced Polypropylene Composites' *PhD Thesis, University of Nottingham, March 1997*

Annex

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Labor and Procurements	$12,622.00 (£7,888.75)
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