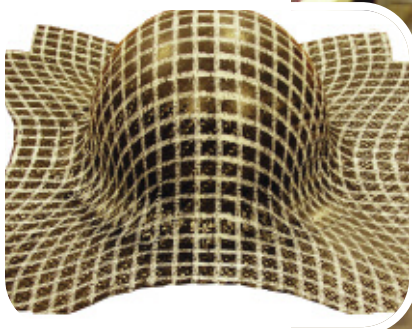
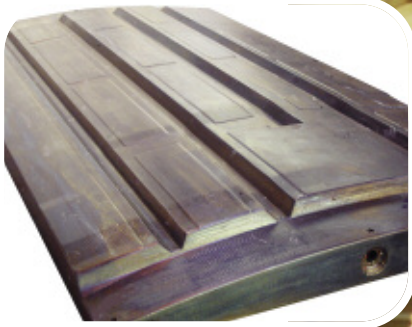
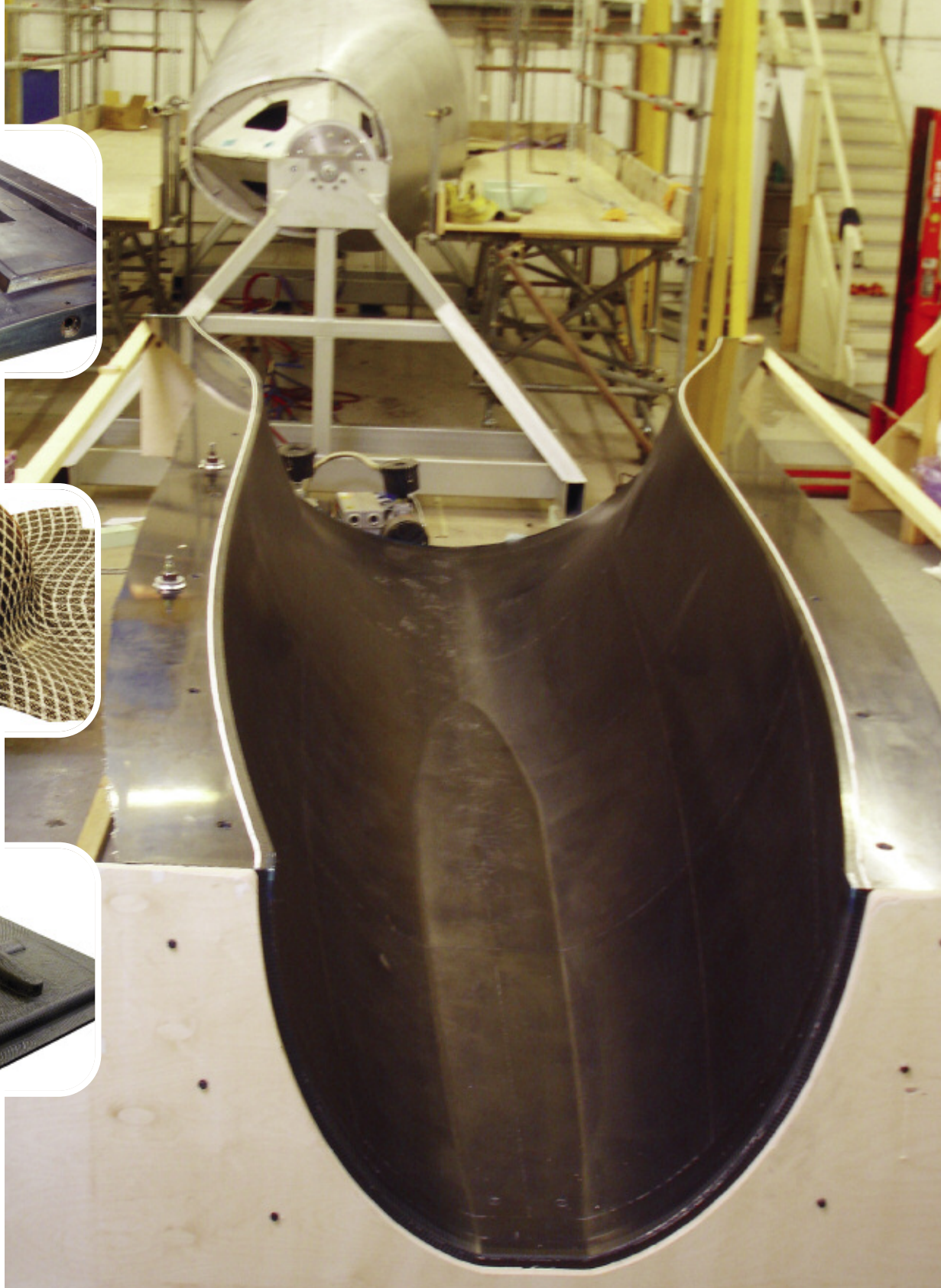


Technical Report - New Tooling Developments

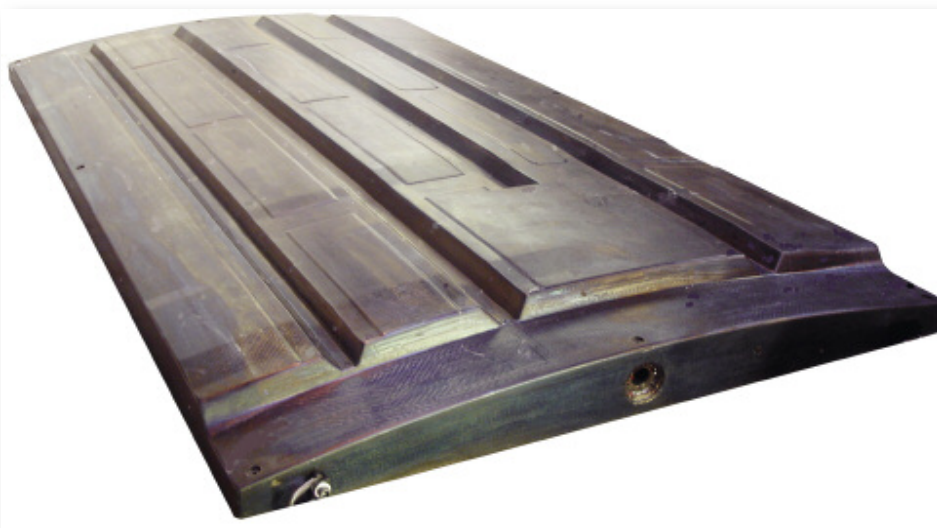


New Tooling Developments: ACG - Pushing the Boundaries of Possibility

ACG GRAFOAM® FPA-20 Carbon Foam Tooling System

GrafTech International Ltd is one of the world's largest manufacturers of graphite and carbon-based products. Their partnership with Advanced Composites Group Ltd (ACG) provides a strong alliance that will see the proliferation of composite tooling technology into exciting new areas.

After nearly 2 years' research and development at ACG's Technology Centre, the processing and performance requirements of ACG GRAFOAM FPA-20 Carbon Foam Tooling System have now been fully characterised. It is now hoped that the carbon foam product, combined with associated novel technologies, will enable exciting new concepts in low CTE, low mass composite tooling.



ACG GRAFOAM® FPA-20 Carbon Foam Tooling System not only exhibits an extremely low CTE ($2.3 \times 10^{-6}/^{\circ}\text{C}$), but it also has a thermal resistance that exceeds composite processing requirements.

Furthermore, it can be rapidly machined to near-finished size and then fully encapsulated in ACG's proprietary, patented, compliant interface technology

and a tooling laminate skin, typically ACG's Low Temperature Moulding (LTM®). However, the inherent thermal qualities of the carbon foam also allow the application of higher temperature resin systems from ACG's medium (MTM®) and high (HTM®) temperature tooling laminate ranges.

Once cured, the final tool profile is created with a second machining operation, overcoming many of the problems encountered with the usual master model approach, such as shrinkage, spring-in/spring-out, and pattern/laminate CTE mismatch. Any further tooling modifications can be achieved with additional local lamination and subsequent re-machining.

Tools manufactured from ACG GRAFOAM® FPA-20 Carbon Foam Tooling System are fully self-supporting, and are suitable for

traditional and emerging composite process methods, particularly tape placement and filament winding, where low weight is a major benefit when manipulating extremely large tools, the latter of which is a major issue with Invar or other metallic tooling.

Large development tools, manufactured at ACG's facilities for a major aircraft manufacturer in North America, have achieved dimensional accuracy of 0.2mm on particularly complex surface profiles, but with the vast majority falling within $\pm 0.1\text{mm}$.

The high thermal resistance of the ACG GRAFOAM® FPA-20 Carbon Foam Tooling System offers significant advantages and cost savings when manufacturing high

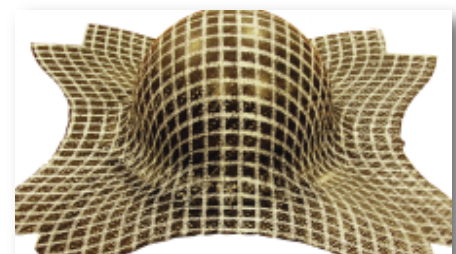
temperature (BMI) tooling. With no requirement for a master model, ACG BMI prepreg can be cured directly onto the foam core in a single operation, without the need for a heat-resistant intermediate splash tool, and then machined to the requisite final profile.

ACG DForm™ Deformable Composite System (DCS) for Tooling

ACG's DForm™ (patents pending) is a labour and cost-saving prepreg technology which combines the conformability of a short fibre moulding compound with the directional characteristics of a high performance, long fibre composite.

Previewed at JEC 2008, ACG's DForm™ has undergone extensive market testing and, more recently, new custom-built processing equipment has been installed at ACG's Heanor manufacturing facility to further enhance the product and accelerate productivity rates to satisfy anticipated market demand.

DForm™ is particularly suited to the manufacture of composite tooling, offering a number of advantages over standard long fibre woven fabric prepreg, and random short fibre and infusion tooling systems.



DForm™ offers considerable savings, typically up to 50%, in lay-up time. The unidirectional fibre structure of DForm™ maintains dimensional accuracy and performance predictability. It creates an extremely flat, print-through-free surface

profile with no local thinning, no loss of fibre orientation or variation in resin content, all of which are issues that can compromise random short fibre, wet lay-up and resin infusion tooling systems.



Out of Autoclave (OOA) Tooling Update

The size of next generation commercial aircraft has focused attention on the need for new processing routes for components, and also for the tooling in which they will be made. So why adopt OOA processing?

- Cost - larger parts mean larger autoclaves, with potential costs spiralling ever upward.
- Time - the demand grows for more and even larger composite parts to ever tighter timescales.
- Work-Share - if components can be produced OOA then this greatly increases the potential industrial sub-contract base for OEM's.

Away from the aerospace market, development has moved at a frantic pace, and ACG has led the way in large scale OOA component and tooling developments.

In the marine and wind energy markets, ACG has had first-hand experience of larger composite components and associated tooling.

Other potential tooling routes, such as wet lay-up and resin infusion, have proved inconsistent and often high risk options for large one-offs built to very tight time scales.

Prepreg has become the tooling material of choice, but, with the materials developments pioneered at ACG, the 'secret' to these materials is the air release fibre architecture, which facilitates the removal of air during the curing process, producing the surface quality, longevity and integrity that tooling applications demand.

ACG's ZPREG® partially impregnated rapid laminating systems have been specifically formatted for rapid tool construction, with no intermediate 'debulking' cycles.

ACG recently completed the manufacture of a large rear fuselage tool using its OOA partial impregnation ZPREG® tooling surface plies and high temperature tooling bulk ply. Autoclave tested for vacuum integrity up to 190°C (375°F) at 90psi (6.2bar), the tooling showed no leakage and produced an excellent surface finish.

Composite technology moves on; autoclave processing has, to date, dominated the aerospace industry. Aircraft are becoming ever larger so the processing technologies must be adjusted to accommodate this, and tooling development must follow. Here, at ACG, we think we have the OOA answers.

Caul Sheets

Another issue, which is a direct consequence of the growing size of commercial aircraft and the increasing importance of OOA processing of large components, is the demand for extremely large caul sheets to control part thickness and back face surface quality. Not only must these potentially very large (and very thin) structures withstand the elevated temperatures of aerospace cure cycles, but they must also offer mechanical handling performance far in excess of anything previously demanded from a tooling material.

Once again, ACG has drawn on its OOA experience and next generation of high toughness resins to bring about the development of high surface quality, robust caul sheets which will withstand the handling techniques and high temperatures associated with modern OOA aerospace production environments.

Metallic Coatings for Tooling

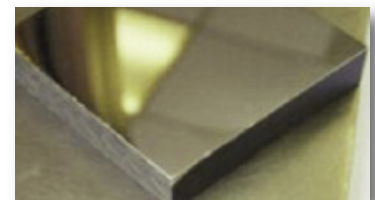
ACG and Toronto-based Integran Technologies Inc recently reached Phase 2 in a Joint Development Agreement for advanced carbon fibre composite tooling solutions based upon Integran's Nanovate NV® technology platform.

Nanovate NV®, a low thermal expansion metal coating, increases the surface hardness of a carbon fibre composite tool surface by up to 15 times, thereby improving tooling durability and longevity. Ongoing development work has enhanced the bonding integrity of the metallic coating to the surface of the composite tooling laminate, extending tooling life in demanding production environments and, consequently, significantly reducing manufacturing and maintenance costs.

ACG is now actively seeking suitable trial application opportunities and would welcome enquiries from interested parties. Initially, these tools will be limited to 1.5 x 1.5m (width and depth).



Tool undergoing vacuum integrity trials. Image courtesy of EADS CASA.



Machined Composite Tool Skins

Composite tooling is usually moulded net-shape from a machined master model. Such master models are often generated direct from a CAD profile and 5-axis CNC machined to mirror the outline. The tool is then laminated on the master model and cured with some adjustment of the initial cure temperature and post-cure temperatures to compensate for master model expansion and prepreg resin matrix shrinkage, all of which can result in dimensional mismatch and angular rotation (spring-in/spring-out).

Surface machining can potentially compensate for the inaccuracies introduced by tool skin laminate

shrinkage and spring, thereby resulting in improved accuracy. This is particularly important where exact CTEs are unknown or where several different materials have been used to manufacture master models.

A recent programme of work, carried out by ACG on a range of autoclave and vacuum bag cured tooling, has demonstrated that, even after heavy machining, there is no loss of vacuum integrity and that very high surface quality and exceptional dimensional accuracy can be achieved.

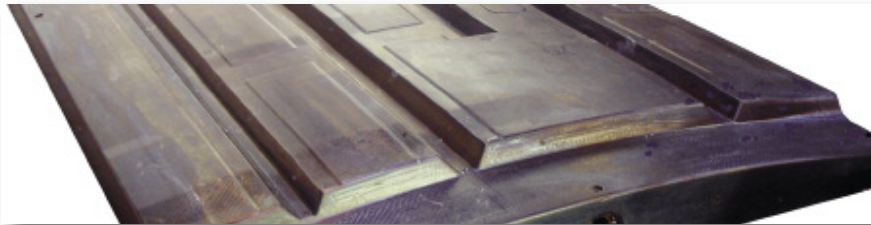
Trials on a standard 1-8-1 laminate have shown that, even after successively machining operations to remove 1mm layers (with the laminate eventually reduced from 5.5mm to

2mm), there was no loss of vacuum integrity.

From a machining standpoint, poly crystalline diamond-coated cutters have been identified as being the most effective and resistant option for reworking abrasive carbon laminates.

When machining the bag side of a laminate, the flatness of this face is important; clearly, a flatter face requires the removal of less material before a consistent surface profile can be established.

ACG has tested a range of epoxy and Bismalimide (BMI) tooling resins in conjunction with a number of weave styles and weights, including ACG's DForm™. Small differences in surface roughness could be identified, but were found to be negligible after final hand-finishing, and perfectly acceptable for use as a tool surface. Moreover, tests have shown that BMI produces a superior surface profile.



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