SAMPE UK & Ireland – Master Class October 2nd 2013
at National Composites Centre, Bristol.

The Future of Composites Technology: Disruptive Innovation or Sustaining Innovation

Overview

A Master Class was organised to present and discuss major opportunities, possible threats and the challenges arising in the composites industry due to disruptive innovation, that is, "quantum" changes in technology and markets – so called "game changers" - as opposed to more steady evolutionary changes. Nine presentations covering a wide range of subjects were given providing a most educational and enjoyable session. Registered attendees numbered 75 from both academia and industry. Many thanks to Bob Griffiths and David Carlton from SAMPE, and to David Inston of Airbus for organising the meeting, and thanks to NCC for hosting the event.

1. Disruptive Technology or Sustainable Technology? Professor Mike Hinton / NCC

The aims and roles of both Government and NCC in supporting the national composites business were outlined. Total Government spend on critical technologies is around £350m with £30m allocated to NCC for its launch in November 2011. A further £28m was agreed in December 2012 for "NCC- Phase2" which will double the current size of the facility and which is underway. Government recognises the importance of aerospace to UK with £22bn sales in 2010, of which 70% is export. Recently, in March 2013, Government gave a further £2bn funding boost to "Aerospace UK".
NCC's role is to bridge the gap between the expertise of Universities at TRL 1-3 and the needs of industry at TRL 6-9. In addition to aerospace challenges, MH highlighted the huge leap forward in blade size to 80m for wind turbines and the weight reduction targets for automotive, at 200kg by 2020 and a further 200kg by 2030 for domestic cars.
Technical challenges include: larger components, process costs, production rates as parts increase from 10^2 to 10^5 p.a., automation, and growing the UK's skills base. Drivers include: political issues (national, EU, world), globalisation of composites, ground-breaking technical changes and catastrophic events.
Finally MH listed some possible severe disruptions: a shortage of current materials, changes to business models, and deregulation affecting both safety and design rules.

2. Keynote Paper: Composites – A Sustainable Future.
Roger Digby / Exova Ltd.

Exova is the largest independent test house in the world covering a wide range of materials, methods and properties. Sustainability was defined as "the capability to endure" – to endure social, economic, technical and political needs. The remarkable growth and importance of composites was highlighted: in 2010 global sales of £11bn with 10.3% growth, and wind turbines which are expected to grow at 12.8% from 2013-2018. UK alone has 1500 companies in composites with £1.1bn sales. The split in UK sales is £0.45bn GFRP, £0.66bn CFRP, but in volume 87.5 ktonnes and 2.5 ktonnes respectively. There is a 9% p.a. growth in GF compared with a 17% p.a. growth in CF, and UK is growing faster than the rest of Europe. Despite the rising trend, RD highlighted two major problems with composites: high cost of complex parts, and impact damage. The following flow sheet was carefully examined:

Design → Manufacture → Operations → End of Life (disposal)

Design is first and to a large degree, paramount. Here is where cost, quality and performance are locked in: reductions in drag, weight, cost, noise, increased safety margins, comfort and convenience. A key question posed is "do we need the full performance properties we build in at design, as this adversely affects cost and complexity issues all down the line?" As an example, for ease of re-cycling, a minimal 2-phase composite system is ideal, but additional components are typically added to enhance performance (eg toughening agents). The optimum choice is a carefully considered balance.

Exova highlighted the need to maximise focus on analysis as opposed to testing, as the traditional testing sequence incurs exponentially rising costs: coupons →sub-components → components. Finally an "out of the box" concept for revolutionising composite fabrication was introduced by comparison with natural composites, wood and bone, in which reinforcement and carrier are formed continuously and simultaneously.

3. Back of Cigarette Packet Approach to Composite Property Prediction and Structural Design. Paul Hatton / CT Aerocomposites.

PH stressed the benefits, on occasions, of minimising the erudite components of classical laminate theory, and supplementing these with useful statistical approximations and "rules of thumb". The object is to achieve quick satisfactory answers and to de-mystify composites technology, in order to "convert" metal engineers into the composites world. In this way composites will better "disrupt" the established domain of metals.

Three "simplifiers" were introduced.
(1) the simple rule of mixtures predicts adequately a composite's mechanical performance and density from the basic properties of the components.
(2) satisfactory approximations to classical laminate theory will usefully predict strength, strain and dimensional stability under load of different layups, in particular the Hart-Smith Model, and associated "10% Rule".
(3) logical simplifications to data input often give results within the design-allowable spectrum. For example if the complex geometry of a wing skin (banana cross-section of varying height) is simplified to a rectangular cross-section of "average height", then input of tensile and compression properties alone simulates the bending moment.

PH's lecture gave a renewed look at composite theory allowing the important "wood" to be seen, despite all the complex "trees" of advanced composite design. This is an important part of the disruptive quest to convert metal design engineers away from their metals and their "black metal" approach.

4. The Future of Composites – Disruptive or Sustaining Innovation? Ben Farmer / EADS

BF illustrated the increasing pace of composites usage by both aircraft build rates and the increasing proportion of advanced materials in construction. In 1975 Airbus forecast the total market need for the A320 at 300a/c; the requirement now is for 10,000 a/c, 5000 of which are already supplied and the remainder on a healthy forward order book. The A350 comprises 53% composites and 14% titanium.
Work at EADS has focused on optimising composite performance by producing the "perfect composite solution":

- (i) high V_f,
- (ii) high aspect ratio,
- (iii) controlled alignment and orientation
- (iv) 3D continuity.

Regarding item (iv), the quest to emulate nature was highlighted by the efficient structures of bone and wood; these involve "bottom-up" assembly with no joints or fasteners.

Last but not least we need enhanced compression after impact, and current work used carbon nanotubes (CNT) since compression is as high as tensile. Work focused on better methods for handling bulk polymers in composite fabrication – (a) material jetting (b) polymer binder jetting (c) extrusion (d) powder bed fusion (e) sheet lamination.

Three fibre / resin routes were explored in detail.
Continuous extrusion in a die with molten resin introduced normal to the fibre tow works quite well with the target properties (i) and (ii) achieving target, but the rest only marginally achieved. Powder bed fusion did not give the target properties sought. CNT + PEEK fabricated in a photopolymer "vat" gave excellent properties with the one exception of low Vf. In this process, CNT's are held in cured resin in a vat, and then a second "interlocking" layer of CNT's, embedded in uncured resin, is introduced and the layers photo-polymerised. This process is repeated to build the composite. First results are encouraging and show that at least two fabrication techniques are viable, and work continues.

5. Enhanced Electrical Conductivity of Aerospace Structures by Incorporation of CNT Doped Carrier Materials to Dry Preforms. Paolo Balliochi / Bombardier Aerospace.

This work is funded via the EU 7th Framework Programme. PB explained that mixing CNT's with bulk epoxy resin prior to infusion is unacceptable due to a significant filtering effect and an increase in viscosity. Nano-doping of a thermoplastic carrier was investigated and PA was selected as the best option for dispersions of CNT's from 5% to 25% with reasonable compatibility of melt temperature with that of the epoxy cure temperature. However, fabrication was not entirely satisfactory and properties, as expected, were adversely affected due to the moisture absorption of the thermoplastic. So addition of CNT's to dry preforms is required. The project's target is to enhance conductivity with no deterioration in the epoxy composite properties. One possible application is lightning strike.

A 12gsm thermoplastic nonwoven veil was doped with CNT's and inserted between each laminate layer. However there was no improvement in transverse electrical conductivity, and the inter-laminar fracture toughness, G1c, was reduced by CNT addition. Further work includes: (i) CNT-doped lower basis weight nonwovens at around 6gsm (ii) CNT-doped lightweight copper mesh at approx 150gsm (iii) "buckypaper" fully encapsulated between two layers of resin, but health and safety issues may apply (iv) the use of intermediate temperature PA resin carrier.

6. <u>A Vision of an Aircraft of the Future (and how we can make it).</u>
<u>Dave Inston / Airbus</u>

DI challenged us to "think out of the box", and began the lecture by reviewing some dramatic historical disruptive technologies, the prime example of which was Henry Ford's automation of car manufacture which not only replaced horse carriages but also snuffed out "bespoke", elite, very low volume car-making at the turn of the 20^{th} century. The key word is "affordability" which made high speed transport possible for individuals worldwide. DI stressed that disruptive technology can both change existing markets and create totally new markets. As a futuristic example DI showed graphics of PAV's – Personal Airborne Vehicles.
Regarding aircraft market needs, a large recent user-survey revealed that over 80% of people want

- (i) more sustainability (continued and increasing availability)
- (ii) less fuel burn
- (iii) less noise.

DI then explained that low cost is the most important factor in the composites equation and is essential in order to be able to compete seriously with aluminium. A long list of cost factors, and required changes to current procedures were given:

- (i) a move to out-of-autoclave fabrication as AC / oven processing has low energy-efficiency
- (ii) better and increased NDT
- (iii) recycling – soon partial combustion won't be acceptable and resins designed for recycling must be developed
- (iv) must reduce joints, fasteners and drilled holes which are both expensive and reduce mechanical properties. We need to move to larger co-cured, co-bonded structures. DI stated the motto: "more glueing, less screwing"
- (v) prepreg handling is time-consuming and various future alternatives were given, eg. large scale vacuum resin infusion (as yacht-makers are using successfully and routinely), refined resin infusion, hollow pultrusion sections slotted inside each other to give long, honeycomb-type structures, each sub-component partially cured, assembled, jigged and then completely cured
- (vi) long cure equates to high cost, but epoxies are available which cure in 2 minutes and should be adapted for aerospace, and should require no toughening agents (vi) lightweight tooling
- (vii) heat transfer liquid curing, eg Quickstep, which saves at least 80% of energy compared with autoclave, due to the high efficiency of convection compared with conduction.

Finally DI touched on new materials: new fibres, CF tapes, NCF's, 3-D wovens, and gave an example of 3-D / RTM used in an engine shroud which saves 1000kg per aircraft

7. <u>Back to the Future - Fibre Technologies.</u>
<u>David Groves / NCC</u>

DG began by reviewing what the different markets require as priorities from advanced fibres and their composites: Sports – performance; Military – performance, quality; Aerospace – performance, quality, cost; Automotive – performance, cost. Military is typically the first to have needs addressed, followed by sports, aerospace and automotive respectively. Fibres were presented generally in ascending order of modulus.
Firstly the inorganic fibres: E glass, S glass, and basalt fibre (eg Kamenny Vek, Ukraine) made from crushed molten rock replacing S glass in some instances. Secondly, polymer fibres: whilst they are used as reinforcements the main use is as single materials - ropes, harnesses and in ballistic protection.
Front-runners are:
PA (eg Kevlar), PE (Dyneema/DSM, Spectra/Honeywell), and finally PBO and PIPD both of which have high mechanical performance (5.8GPa/270GPa, and 7.2GPa/350GPa respectively), and no discrete melting point.
The main activity is with carbon fibres of which their are many types and performance ranges, mainly based on PAN precursor: (i) standard modulus – 235GPa / up to 5GPa UTS (ii) intermediate modulus – 300GPa /3.5GPa (iv) ultra-high modulus CF / pitch based precursor – up to 900GPa stiffness.
Lastly, ceramic fibres were reviewed, including boron fibre which has the benefit of equal tensile/ compression properties but now largely replaced by carbon fibres, and SiC fibres with good tensile properties and 2300 ºC capability, but high cost. Finally diamond fibres were introduced with a remarkable 1220GPa modulus, but with applications still to be determined.

8. Reactive Thermoplastic Composites – A Potential Game-Changer?
Conchur O' Bradaigh / Eirecomposites.

COB (R&D Director and co-owner) gave a brief description of Eirecomposites which has 60 staff and is engaged in aerospace, renewable energy, design and testing. Bombardier and Airbus are large customers. COB is also on the staff at Galway University and together with workers at Limerick University runs the "I Comp" programme with €25m invested in marine renewable energy.

COB quickly reviewed the well-known advantages of thermoplastics (TP): large range of types and properties, rapid processing, environmentally friendly, high toughness, impact resistance, corrosion and solvent resistance, and low FST. In contrast, significant disadvantages include high molecular weight and hence high melt viscosity, and high melt temperatures similar to thermoset (TS) cure temperatures. A graph of melt viscosity vs process temperature showed that the TS vinyl ester (VE) occupies the "sweet spot" combination of the above two properties. PEEK, PPS, PEI and similar polymers are high up in the problem range of the curve, but their respective monomers are lower than the viscosity of vinyl ester, with satisfactory process temperatures between VE and the TP polymers. For example cyclic PBT permits up to 400msec of infiltration time before the viscosity increases to above 1cps.

Work therefore involves the use of monomers with RTM processing and ceramic tooling. Anionically reactive PA12 was screened but rejected due to cost, polymer complexity and low modulus, hence poor support of CF in compression. Work with Engel (Germany) focuses on caprolactam (precursor to nylon 6/6) with the viscosity of water, since reactive PA6 ticks all above boxes. Good, rapid bonding between the fibres and the polymerising resin is essential and COB drew parallels with what is achieved with the BMWi3 electric vehicle (RTM /CF/epoxy) which uses specially surface bonded fibres to give less than 100 seconds mould-time and a process therefore which is cost-competitive with metals and necessary for target production rates of 1m parts pa

In conclusion COB advised that the future for reactive TP's is good although the current systems are not yet ready commercially for many industries. Success in the future requires robust, tailored fibre and polymer chemistry (fibre sizing).

9. The Future Design for Manufacture. Prof Kevin Potter / Bristol University

KP posed the question: why after 40 years does the composite industry still have significant recurring problems with reliable processing and costs? The focus of the lecture was "Design for Manufacture" (dfm) which as a prerequisite must enable the product to be manufactured without undue complexity or difficulty.

Up to 70% of the product life cycle cost is committed at the initial design stage, ie the dfm stage. The most essential question is "Step 1" in the design / planning sequence which asks, "is the input geometry suitable for automated manufacture?" A logical and methodical flow chart of "Yes / No" answers to a cascade of inter-connected questions then follows, all aimed to achieve the optimum solution to Step 1.

Of the many inputs to successful production few, if any, are genuine specific composite inputs. For example, product and structural design, materials responses, machinery design, programming and operations, skills and training, factory services are all basic factory operational factors. "Right first time" is essential. Importantly, most defects relate to design faults, and not to manufacturing faults.

Minor changes in part geometry can cause significant defects and cost escalation, even when exactly the same production process is being used, and so must be questioned. For example in a gently "waisted" cross-section, as opposed to one with flat / rectangular shape, as the angle of waist (layer run out in the mould) increases from 5º to 70º the layup time increases x6. Also, automated fibre placement, whilst introduced to reduce times and costs, is in fact very restrictive on shapes and so has attendant problems.

KP then moved to problems in the UK composites skills base. A recent survey showed the average expertise is greater than 30 years, range 15-40 years; technicians retire faster than they are recruited! Growth in new sectors adds problems and fragmentation of the supply chain makes it even worse. There will be a net decline in expertise as people retire from the industry.

Regarding the concept of designing a "new" composite process, KP stressed the key requirements for well-aligned short fibres, good fibre re-cycling and the capability for hybridisation. Short fibres are best for reducing ply-drop stress concentrations and usually cause no reduction in mechanical performance. In many instances traditional continuous fibres actually add processing difficulties, and cannot be used successfully in double-curvature structures due to gapping. KP explained the procedure of tow shearing as opposed to tow steering, the former enabling the minimum radius of curvature to be reduced by up to 90%. Combining this technique with short fibres adds additional curvature enhancements.

In conclusion KP urged the industry to take two steps back to re-evaluate where we are now, and why, and to go right back to initial design. We should do this now, and addressing the issue of replacement of skills is urgent. The lecture stimulated much discussion, not least of which was the dichotomy between developing multi-skills including on-job training, and the perceived associated immediate cost penalty, with the economy of the vertical organization, where each person does only their own expert part of the process chain. The view was that short-termism will prove very much more costly in the long run.