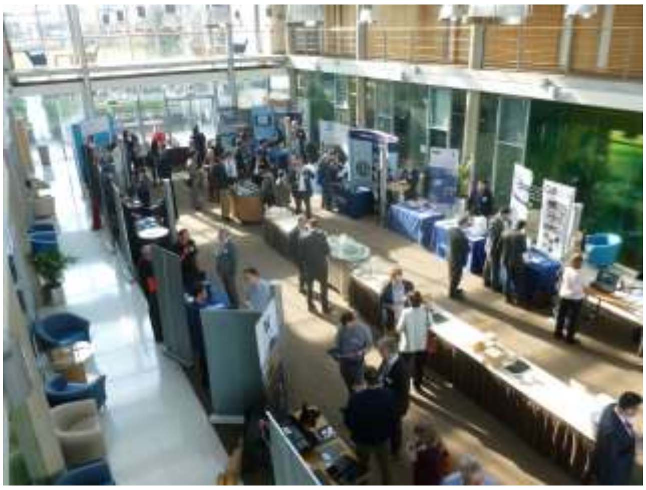
SAMPE UK and Ireland (SUKIC) Annual Seminar and SME Table Top Exhibition

Breakthrough Technologies for Advanced Composite Manufacture

National College for Teaching and Leadership: Jubilee Campus,
University of Nottingham
Thursday 25th February 2016

This year's seminar followed the success of previous events with 100 delegates, 20 exhibitors and 8 presentations. Thanks are due to TenCate Advanced Composites for sponsorship, supported by to the University of Nottingham and to Trevor Cook and David Carlton for organisation.



1. **Keynote Presentation**:

Aerospace Composite Manufacturing Technologies including Thermoplastics and related Automotive Applications
Art Offringa, Fokker

- An overview was given of Fokker's activities with materials and assembly formerly with epoxies but now with increasing use of thermoplastic resins. The weight saving advantage of composites over aluminium is increasingly important as the trend continues to larger commercial aircraft and to larger and heavier engines. The corrosion advantage of composites over aluminium was also highlighted allowing the overhaul on the Boeing 787 for example to be extended from 6 years to 13 years.
- The basic material benefits of thermoplastics versus thermosets were summarised with particular focus on the benefits in assembly regarding cost and versatility in complex structures. For example the *thermofolding* of curved laminates gives not only cost reductions compared with more complex thermoset lay-up but it is recyclable (remouldable). Also the higher

toughness compared with epoxy resin allows weight reduction. Similarly *press forming* gives a 30% cost reduction compared with conventional technology

- The large cost savings and process simplification allowed by thermoplastic *welding* were highlighted, which reduces or completely removes the need for mechanical fasteners. Three different types of welding were explained which can be completed in 1 to 5 minutes: ultrasonic, resistance and induction welding.
- The *co-consolidation* of large structures, for example fuselage sections, and the butt-jointing of thermoplastic parts were further described as key technical attributes of the material. Thin fuselages are prone to damage; therefore thermoplastics provide higher toughness. A new concept developed by Fokker is the manufacture of both frame and skin in a single part. No, or minimal rivets are required with these all-thermoplastic stringers.
- The material choice for thermoplastics is wide-ranging in both cost and performance. For automotive applications PP and PA tend to be used with a process time as low as 1 minute whereas aerospace parts typically use PS, PES, PEEK and others, with increased melting point and temperature capability.

2. ***Fibre Preforms for Automotive Applications*** **Stefan Voskamp, Eurocarbon**

- The long history of braiding, which has origins in the 18th century, to produce fancy textile goods mainly for the female garment business, was briefly reviewed.
- Eurocarbon was founded by Stefan's father in 1982 with the specific aim of supplying the composites market with elaborate braided fibre reinforcements using carbon fibre. Initially the braiding process converted fibre tows in to hollow tubes which were used, as produced, for the reinforcement of cylindrical structures for example in some sports goods. Alternatively, the braids could be slit to give 2-D multi axial reinforcements with more structural versatility than fabrics.
- In 1994 Eurocarbon introduced an *overbraiding* process in which fibres are layed down on to a core, similar to filament winding, but with many advantages. The core can remain in-situ as part of the final component, or can be removed. Removable cores include polystyrene foam, wood, metal and soluble inorganics.
- Eurocarbon's largest overbraiding machine, built in-house, has a fibre feed carrier to accommodate 144 or 288 spools. Half the spools move in a clockwise direction and half in an anti-clockwise direction. The fibres are placed directly on to the core with very high deposition rate and with waste at less than 10%. The multi-axial structures produced can be tailored to suit application, where the bias / UD ratios can varied from extremes of 15% / 85% with independent control of the fibre cover factor (areal weight). Hence the crash properties and the load bearing ability are excellent, both in bending and in torsion.
- Automotive applications include the Mercedes McLaren SLR crash core, the Lamborghini A-pillar and the BMW 7 series roof beam.

3. ***Application of Composite Materials to Turbine Engine Components***
Daniel Dunn, GE Aviation.

- As expected the driver to use composite materials in jet engines is weight reduction and hence lower fuel burn. Although aircraft fuselage weight has been decreased with composites, the trend to higher-thrust engines (measured as engine pressure ratio at cruise) has increased the specific fuel burn. The GE90 turbofan engine is the first in service to use CFRP / polymer matrix composite in the front fan blades. This area is not too hot and the fracture toughness is satisfactory. But moving inside the engine, all PMC's are thermally inadequate.
- Since the mid-1960's hot parts of the gas turbine engine, e.g. the low and high pressure compressors, the LP and HP turbines and the combustor have been made from nickel-based super alloys. These operate at or near to their melting point and are therefore "super-cooled" to a safe, but still very high temperature, by a high diverted cooling air flow (some Ni blades are perforated with micro-holes to cool their interior).
- Monolithic ceramics have higher temperature capability than Ni, are stiffer and strong, but are brittle and lack adequate fracture toughness, so ceramic matrix composites (CMC's) are required. CMC's have had many technical and economic challenges to overcome and the development time has been long, but GE has overcome these obstacles and will supply the (static) HP turbine shroud for the best-selling LEAP engine. (GE also has rotating CMC parts on advanced tests for a military demonstrator).
- The optimum CMC of choice is Sic_f/Sic_m (silicon carbide fibre and matrix) with an operating temperature of approx 2000 ºC, at least 100ºC to 200 ºC above the capability of the Ni alloy. This is a large difference and huge advantage, enabling reduced / minimal direct cooling of parts with smaller units, and importantly the more efficient use of available air to aid fuel combustion and hence increase engine efficiency. Most importantly the CMC is just $1/3^{rd}$ the weight of nickel. For high speed rotating parts this gives more than a basic pro rata weight saving because the lower mass reduces the centrifugal force and allows thinner discs, smaller bearings and other parts.
- High speed video films were shown of a lab test where a ¼ inch thick CMC and a monolithic ceramic comparator were impacted with a ball fired at 190m/sec. The monolithic was destroyed, and the ball continued travel, whereas the CMC suffered local damage only, remained intact, and the ball bounced back.
- A brief description of the CMC process was outlined and contrasted with the relatively simple process chain for a PMC. Since fibre and matrix are both SiC, the interface is too strong and would result in brittle failure, so a CVD (chemical vapour deposition) coating is applied to fibre. The fibre then goes through a matrix slurry of an organo-silicon complex with added Si particles, is drum-wound and dried, then cut and layed up. The matrix then requires pyrolysis at 1400 ºC to remove the organic elements and to convert to SiC. The final stage is the application of an environmental barrier coating (EBC). Although SiC is oxidation resistant due to the formation of a passive coating, this is not the case when water vapour is present as in the hot zone of the engine after combustion.
- The LEAP engine programme is controlled by CFM International, a joint venture company of GE and SNECMA.

4. ***Thermoplastic Materials – Innovation and Value Creation***
Nick Tiffin, TenCate

- TenCate has T/O of €1.6bn, is listed on the NYSE and has 4500 employees worldwide. It grows by acquisition with a strategy of "Buy and Build", the latest being Amber Composites.
- TenCate is a large-scale manufacturer of finished components and semi-finished products for aerospace, automotive and industrial applications. Thermoset aerospace applications include radomes, satellites, and parts for military and commercial aircraft.
- TenCate commenced composites production in 1972 and introduced the first thermoplastic aerospace parts in 1989. Thermoplastic products are sold under the Cetex trade name. A comprehensive range of products is produced including finished components, U/D tapes and fabric prepregs, and moulding compounds. Thermoplastic materials include PEEK, PEI and PS for high end aerospace applications and PA, PU, PC and PP for automotive use.
- The usual advantages of thermoplastics over thermosets were highlighted including the ability to weld components, as described also by Fokker. Tencate operate an "over-moulding" process which combines stamp forming with injection moulding allowing the use of long fibres. They are working also with TriMack USA on a novel hybrid moulding process.

5. ***Innovations in Composites at Rolls-Royce***
James Lee, Rolls-Royce

- A large growth in the use of composite materials in RR from 2008 to 2020 has occurred and is forecast. This has been driven by automation and the availability of higher temperature resins.
- Composite applications include civil and military aircraft engines, ground-based power systems, marine and nuclear components. The increased efficiency of aero engines over the above period, example Trent, XWB and Ultrafan, has necessitated the increased use of lightweight composites. The Trent 1000 engine used only 5% composites whereas the ALPS has 65% composite use and a weight saving of 500 lbs.
- The design challenges with composites are specific, and design must be optimised not only for normal operation but also for fatigue and foreign object damage.
- A number of specific composite innovations were summarised in particular a carbon fibre / titanium blade, a spinner core and annulus filler. Current developments include novel through thickness technology and automated visual inspection.

6. ***Robot Layup Techniques***
Michael Elkington, University of Bristol

- Bristol is part of a research unit, Advanced Composites Centre for Innovation and Science (ACCIS) which includes the Universities of Cranfield, Nottingham and Manchester. A primary aim is "High Quality Manufacturing." Specifically, the work at Bristol examines whether manufacture of a satisfactory quality can be devised from an upgraded process between the extremes of basic hand layup and AFP / ATP automatic fibre placement and automatic tape laying). Hand layup would be replaced with robotic layup.

- Detailed video analysis was made of the hand layup of 9 different parts. A total of 14 laminators with various degrees of experience, was included in the analysis. Data analysis showed that there were a very large number of separate hand movements with all laminators, but these could be rationalised to a total of 7 basic techniques. These mainly concern the smoothing and crease removal of fabric layers as they are placed into the mould.
- The first observation is that these manual techniques are difficult to automate. Some success has been achieved by breaking down a single complex process in to two simpler processes which are then programmed on computer. 2D fabrics often need "pre-shearing", i.e. pulling at opposite corners to remove creases and fibre mis-alignment. This is simulated on computer by a rectangle superimposed on the fabric surface and angled at 45º to the fabric sides. This is then pulled by a shear force in to a square shape.
- Special tools are made for the robotic arms to simulate the hand, finger tip and nail, for example round ball rollers and elliptical rollers of various shapes. Work continues making additional rollers and probes as required.

7. *Joining of Composites to Metals by Biomimetic Concepts*
Evangelos Avgoulas, University of Cambridge

- Evangelos is the winner of the UK 2015 student seminar competition.
- Biomimetics is used to examine how nature achieves bonding particularly between materials with different stiffness for example bone and tissue. Nature's solution is to use a graded interface bond strength along the joint line between the softer and stiffer material.
- CFRP and steel plates have been bonded together using both standard steel sheet and steel sheet which has been perforated with drilled holes. The perforated steel plate has a gradation of hole size, running from small at one end to large at the other end, in order to affect a differential in the stiffness of the steel running along the bond line.
- Detailed tensile testing and numerical analysis has been carried out including high speed video film at 16K frames per second of the failure mode. Failure is fast at 0.2 milliseconds. Compared with non-perforated steel the perforated steel achieves a 175% increase in joint strength with the CFRP.
- Work continues on a practical component where CFRP is bonded to steel in a propeller root for GE Aviation / Dowty Propellers.

8. *CFC Usage and Future Strategy at Jaguar Land Rover*
Rebecca Hitch, Jaguar Land Rover

- The environmental challenge is to reduce CO_2 emissions. The technical challenge is not only in the design and manufacture of lightweight vehicles but in the reduction of parasitic energy loss, for example in aerodynamics. The introduction of electric and hybrid vehicles is environmentally beneficial but the batteries used are very heavy.
- The main thrust of the presentation was that although there has been an increase in the use of CFRP and other composites over the years, JLR operate a mixed materials approach; there is still a vital role for metals and polymers alongside composites to achieve the required

environmental and performance requirements. Testing requirements are rigorous with impact resistance measured at 4x the vehicle weight.

- Progress with metals continues. There has been a steady replacement of some steel with aluminium giving a 40% weight saving. Smaller powertrains give improved fuel economy and reduced CO_2. Rivet bonding is lower cost than metal welding. Up to 50% of the aluminium sheet used is recycled.
- The selection of materials is based on the criterion of weight saving / performance versus cost increase. Aluminium is 2x the cost of steel with a 40% weight saving. CFRP gives at least a 60% weight saving over steel but is 20x higher cost. The Range Rover Evoque demonstrates the mixed materials approach: 45% steel, Al roof and hood, polymer front fender, SMC tailgate.
- The JLR composites timeline was summarised as:

  2011 glass / PP (high volume parts, short cycle time)
  2014 CFRP roof
  2018 the "Varcity" vehicle
  2020+ CFRP intensive vehicle

  The two main drivers and enablers for composites are NVH and repair strategy (BVID)
- The Jaguar F-Type composite roof has a cycle time of just 5-10 minutes. The Varcity will save 100kg of body weight plus improved attribute performance.
- JLR's composites and materials future was described as

  CFRP for crash / strength parts
  Metals for crash / crush parts
  Polymers for non-structural weight saving
  In summary: "The Right Material for the Right Part"

Exhibitors

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