Marine composites – drawbacks and successes

George Marsh reports from a recent international conference on Maritime and Offshore Composites, held by the Royal Institute of Naval Architects (RINA) in London.

Reinforced plastics offer formidable advantages for high-integrity maritime structures. However, there have been a number of ‘roadblocks’ preventing these materials, at least at the more engineered end of the spectrum, from fulfilling their full potential. A primary theme of the conference was that these hindrances are progressively being addressed, while a growing track record of successful application should serve to encourage designers and manufacturers to place greater reliance on composites.

An undesirable feature of composite structures is variability, even between copies of the same basic structure produced at different ship and boat yards. Differences in quality, properties and cost result from variations in design and manufacturing procedures. Researchers from Southampton University, UK, outlined an approach to reducing this variance, at the same time showing how structures might be produced at lower cost without sacrificing structural integrity.

Messrs Sobey, Blake and Shenoi highlighted the all-too common disconnect between structural designers and manufacturers in which designers operate first and then hand off their designs to the manufacturing department which goes on to produce the final structure. Despite ‘design for production’ being an old idea, this sequence ensures that departmentalism prevails and those areas needing to make the highest levels of compromise have the least communication. As a result, structures are often both variable in quality and costly because they are hard to manufacture. Better, it was suggested, would be a concurrent engineering approach whereby designers and fabricators work closely together so that producibility is built in from the start.

Achieving meaningful communication between professional specialisms can be a challenge and requires a concurrent engineering environment that encourages it. At the same time, to prevent the ‘endless meetings’ syndrome, such interplay must be targeted and structured around specific project requirements. The Southampton group went further, arguing that much of the inevitable routine communication can be automated, reserving direct face-to-face meetings for matters requiring high-level collaborative decision making.
Automation would comprise a central database in which intellectual input from all parties is combined, along with extensive modelling of design and production processes. Embraced within an ideal model would be material properties, classification society rules, customer requirements, and previous experience with structural designs, both successful and flawed. A benefit of the latter is that encapsulating a company's accumulated design wisdom in a model reduces reliance on design gurus who are increasingly apt to move on, tempted by prospects elsewhere. From the model, engineers can rapidly gain an appreciation of where previous errors have added to expense or resulted in non-optimum structures.

The researchers outlined the development of an automated tool combining the use of optimisation and reliability techniques, aided by genetic algorithms, Monte Carlo simulation and other software elements. The tool would enable a much more integral design and manufacturing process to take place iteratively, with optimisation occurring at each stage. Designs would be optimised for mass, performance and cost.

Developing such a tool is challenging. To be useful, it must be easy to learn and use, interfaceable with the disparate IT systems serving different constructors, and able to be introduced unobtrusively alongside current software. While being industry specific, it would have to allow for individual company idiosyncrasies. A software package meeting these criteria should help ensure that composites are applied to best advantage and at lowest cost consistent with meeting structural requirements.

Qualification issue

A feature of composites that is both a strength and a weakness is their chameleon-like adaptability to a wide range of applications on the one hand, and their variability on the other. It can seem that there are almost as many product and process variations as there are individual structures, a fact that makes it difficult to formulate industry standards and qualification routes.

This was acknowledged in a paper by Messrs Weitzenboeck, Hayman, Hersvik, McGeorge, Noury and Hill of Norwegian classification society Det Norske Veritas (DNV) and Echtermeyer from the Norwegian University of Science and Technology. Neverthelss, standards are essential and the authors' joint experience in evolving them illuminated their discussion of a number of case examples.

Wind turbine blades are a topical instance. Emergence of the DNV Offshore Standard for the Design and Manufacture of Wind Turbine Blades (DNV-OS-J102) provides a comfort zone by offering a contractual reference for contractors and their clients as well as guidelines for designers and manufacturers. Based on DNV's 20 years of experience in certifying wind turbine blades, the standard provides a firm foundation for
Why composite patch repair? (Source: DNV.)

A new in-mould gel-coat process relies on a separator layer between the laminate and the gel-coat. (Source: University of Plymouth.)

Why composite patch repair? (Source: DNV.)

A presentation from the IMCB-Institute of Composite Materials and CNR-Biomedical National Research Council in Italy highlighted the beneficial flame retardancy achieved by adding zinc-based compounds to epoxy matrices. Authors De Fenzo, Formicola, Antonucci, Zarrelli, and Giordano pointed out that unaltered epoxy resin ignites at some 400°C, subsequently reducing to a char but producing large volumes of harmful smoke as it does so. The smoke is due to a high yield from the resin of flammable volatiles.

It is known that certain compounds of zinc and tin can be effective in suppressing these emissions and hence the harmful smoke. They do this by slowing down the combustion process, ‘staging’ it so that there is a higher char yield than with neat resin. As a result, less of the material literally goes up in smoke. Tests carried out in Italy showed that zinc borate, zinc stannate and zinc hydroxystannate used as additives in a low-viscosity toughened epoxy resin intended for resin transfer moulding (RTM) and vacuum infusion proved effective as flame retardants. A model of the degradation process was developed.

A submission by the UK branch of classification society ABS on structural fire protection for FRP yachts outlined an
intended theoretical model for predicting the behaviour of composite elements under specified heat loads. Successful validation of the model in actual fire tests would assist in developing draft standards to help designers provide effective protection against both resin ignition and harmful emissions after ignition. The ISO TC8/TC12/WG2 project team welcomes comments and input.

**Boosting confidence**

Some potential applications are held back because of deep-rooted perceptions that plastics cannot have the same structural integrity as metals or, even if they can, that integrity will not be as prolonged. An answer to this, according to Messrs Walker and Faulkner of Tangent Technologies Ltd, is to boost would-be user confidence by providing integrity monitoring – not via external scanning or even surface-mounted sensors, but by tiny sensors embedded within the composite itself. Such on-going in-service monitoring implemented across a range of structures and applications could, they told delegates, convince sceptics that composite structures can indeed have and maintain high integrity. Moreover, being able to provide regulatory authorities at any time with periodic data indicating fitness for service might exempt structures from disruptive scheduled inspections.

Use of scanning acoustic non-destructive evaluation (NDE) is a well established technique but Tangent Technologies, in collaboration with FE Composites Ltd, have internalised the process by embedding small acoustic sensors within the composite. The sensors used can survive composite manufacturing processes and can be positioned to achieve acoustic coupling with key layers in the laminate. The two companies contend that continually monitoring the integrity of a structure in this way throughout service life provides the foundation for condition-based maintenance, with considerable potential economic benefit.

Proof-of-concept sea trials were conducted on a 9 m fast inshore patrol craft. Results are said to have been encouraging, prompting the presenter to conclude that in-service monitoring could be applied to vessels across a wide spectrum of types and sizes, thereby providing awareness over a wide area of the behaviour of a range composite materials in the field.

**Recyclability**

Another objection to conventional reinforced plastics that has come to the fore in recent years with the growth of environmental sensibility is the difficulty of recycling them after completion of their service lives. Landfill and incineration are unattractive end-of-life options, not least because they pose potential health hazards.

Thermoplastics differ from the thermoset resins that dominate today in being recyclable, for instance into injection moulding material, but they have disadvantages of less powerful interfacial resin/fibre bonding and poor adhesion when secondarily bonded. The latter drawback can be overcome by using various local heating methods to ‘weld’ the parts together at their interface. Locally heating parts near the intended bond line from one or both sides melts the thermoplastic matrix, leading to inter-diffusion at the molecular level and consequently a high-quality joint.

Various heating methods have to date been tried including use of incorporated resistive elements, hot gas, friction, electro fusion and ultrasonic methods. An experimental study carried out at the University of Newcastle, UK, has shown that good joints can be achieved with a bulk heating fusion bonding technique that adds no weight or foreign material into the bond line. A paper by Otheguy, Gibson and Robinson described the technique as applied to T-joints and lap joints in glass reinforced polypropylene (PP) material, claiming that the method is highly suitable for small boat builders.

The method relies on vacuum-assisted bulk local heating applied via flexible heaters placed at the bond line. These commercially available silicone rubber insulated electrical heaters can be tailored to any size. Placed on one or both sides of the bond line, the heaters are vacuum bagged, with a breather layer and release film incorporated, so that light vacuum can be applied to the sites during the heating cycle.

The researchers found that best results are obtained by using woven materials and that inclusion of a PP interlayer improves lap shear strength by up to 80%. Overall, they concluded that bulk heating fusion bonding can be an effective joining method suitable for use in small thermoplastic composite boats, providing joints of comparable strength to those conventionally executed in thermosets.

**Gel-coats**

The issue of gel-coats for boat hulls and other marine structures requiring a quality surface finish was addressed in a paper by authors from the University of Plymouth, UK (Summerscales and Hoppins), PERA Innovation (Anstice, Brooks, Wiggers and Yahathugoda), Magnum Venus Plastech Ltd (Harper), W Ball and Sons Ltd (Wood) and Scott Bader Company Ltd (Cooper). Normal methods for applying gel-coats result in volatile organic compound (VOC) emissions and the paper discussed an improved application method suitable for RTM and other closed mould processes.

The patented in-mould gel-coating process involves the use of an impermeable

<table>
<thead>
<tr>
<th>Table illustrating stiffness and strength advantages of carbon composite compared with other materials.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>CFRP</td>
</tr>
<tr>
<td>GRP</td>
</tr>
<tr>
<td>Steel</td>
</tr>
<tr>
<td>Aluminium</td>
</tr>
</tbody>
</table>

(Source: Kockums AB.)
separator layer between the laminate and the gel-coat. Laminates with acceptable surface finish have been produced using the method, which is still under development. It was suggested that, by reducing or obviating harmful emissions, the new process can improve workplace safety and reduce environmental impact.

Confusion
A final disruptive feature of present composite practice was the subject of Plymouth University’s John Summerscales alone, who addressed the confusing set of names and acronyms used by various companies to describe resin infusion processes which, despite their attempts to differentiate them one from another, are basically similar. He proposed a taxonomy under which all the infusion processes can be mapped into four generic processes:
- resin infusion in the plane of the fabric;
- resin infusion with a flow medium/transport or distribution mesh;
- resin film infusion; and
- semi-preg techniques.

These are all resin infusion under flexible tooling (RIFT) processes which occupy, it was argued, the region between RTM and vacuum bagging. Substituting the four-stage taxonomy for the array of name/acronyms used at present (19 were quoted in the paper) should, the author held, make the present situation less confusing.

Inspirational
An inspirational note was struck by two presentations reminding delegates that complete composite ships have been built in Scandinavia and are now well established in service. Operators are enjoying the benefits of reduced fuel consumption (compared with equivalent conventional vessels), along with low maintenance due to the fact that composites do not corrode.

M. Hakansson of Kockums AB, Sweden, said that the rising trend in fuel costs places a growing premium on low-weight design, encouraging the use of advanced composites for hull, deck and other structures.

Kockums has adopted carbon fibre composite as the primary structural material for a new catamaran passenger ferry because it is lighter, stiffer and stronger than the glass fibre that has been the composite mainstay of small craft construction to date, and very much lighter than metal. For example, a structure based on sandwich panels comprising carbon fibre skins over polymer foam or balsa core can be 75% lighter than an equivalent steel structure.

A bar to wider adoption of carbon has been its high price. However, Kockums was able to maintain affordability by making a careful selection of materials, backed by appropriate testing of material combinations and structural forms. Carbon fibre/vinyl ester laminates were used, the fibres being of intermediate strength and significantly less expensive than the strongest, premium grades. Vacuum infusion was the majority production process.

Anders Lonno from the FMV Defence Material Administration in Stockholm reminded delegates that carbon fibre composite in particular has much to contribute to naval craft. Most notably, the 73 m, 650 t, 40 kt Visby class corvette, the first of which was launched in 2000, utilises high-elongation carbon (Toray T700) and a ductile high-density core (Divinycell HD) for its vacuum infused sandwich structure. This has enabled a stealthy design (low radar and magnetic signatures) that is weight optimised so that power requirements and fuel burn are significantly lower than pertain for equivalent metal or glass reinforced plastic (GRP) vessels. Visby, with its use of vacuum infused advanced composites, illustrates the advances that had been achieved in naval composite construction by the turn of the millennium, contrasting with the more basic wet-laid glass/polyester skinned PVC foam core sandwich structures used first employed for mine counter measures vessels in the 1970s.

Yet Visby is no longer the pinnacle of naval composite achievement. In 2010, the further evolved state of the composite art is evident in new Kockums designs for coastguard and combat vessels. Here, a wider range of materials is enlisted to bestowed a broader mix of properties. Sandwich panels are still a preferred structural form due to the high bending resistance they offer together with extra damage tolerance conferred by the presence of what is effectively a double skin. However, skins of carbon, aramid or glass can be specified with a variety of matrix systems and a number of core materials, the mix being tailored according to the properties required. Careful material and process selection enables designers to minimise weight, magnetic signature, radar signature and maintenance, while conferring ballistic protection, and resistance to fire, shock and damage.

Further information
RINA; www.rina.org.uk