Elliott Marine: this short-handed ocean racer illustrates a performance per dollar approach to core selection. Multiple low-cost phenolic-impregnated paper honeycomb cored bulkheads were used to keep the hull shell core requirements low and thus the thicknesses as well. In the forward bottomshell, balsa was used for its 'high strength per dollar' while the rest of the hull was PVC foam cored. The decks used a thin layer of plywood over very low density foam thus reducing core weight while avoiding denting problems.

IVOR WILKINS

# The artisans of compromise

Much debate and opinion has appeared in *Seahorse* recently on the contentious issue of structural problems with composite hulls. Here the High Modulus engineering team present an analytical look at the use of these materials

There has been some fierce debate recently in the letters page of *Seahorse* regarding nearly all aspects of core selection and performance for composite construction. As with virtually all aspects of boat design, the best choice will be a result of compromise.

There is no panacea for all the problems of boat design. The aim of this article is to illustrate through the impartial and practical engineers' selection process, the advantages and limitations of various structural materials as applied to modern boatbuilding. In future articles we will choose individual boats and examine the design from a structural approach, rather than the sailing or handicap point of view, highlighting construction details which can demonstrate specific composite engineering solutions.

The parameters by which structural sandwich cores are chosen, using a typical design approach for a composite vessel, are as follows:

**1.** To meet formal structural design criteria for the behaviour of the hull shell which are most commonly presented by classification societies, such as the American Bureau of Shipping Guide for Building and Classing of Offshore Racing Yachts. These fall into three basic categories:

- bending strength
- stiffness
- shear strength.

**2.** To meet other structural criteria. These are less well defined, but are effectively determined by the designer, based on experience to reflect the requirements of the particular project. These include denting resistance, crushing strength, fatigue and impact resistance.

**3.** Price. The structural engineer does not operate in a costless vacuum, and the final solution must not only fall within a ▶

given budget but also deliver the best possible overall performance. There is no point spending heavily on a specific 'wonder material' if the design will then have to be heavily compromised elsewhere because of cost constraints.

**4.** Processing. Once again the selection is not made solely on the grounds of the structural parameters. If very high resin curing temperatures are required, then the use of certain foam cores will be out of the question, simply because of their inability to handle the processing requirement of a different material in the laminate.

### Detailed specifications

Let us now examine these parameters in more detail, before going on to see how the various cores perform relative to one another in the various categories. Obviously, the easy situation for the specifying engineer to find himself in is when the design brief requires one parameter to be emphasised so heavily that he is pushed into one corner of the selection envelope. More often than not, there is a fairly even three-way pull, and a good knowledge not only of the materials and their relative merits, but also the actual basis of the selection criteria required.

**1. Structural design criteria.** These are the properties required of the hull and deck shell materials to resist the local pressures, or 'heads', caused by water loading, which are usually determined by recourse to a classification society's code. While it is possible to attempt an analysis of maximum possible loads from first principles, the fact of the matter is that a boat hull will probably spend 90 per cent of its operating life at below 30 per cent of its peak loads. A boat hull may bob around for years – or even until it is scrapped – without ever being severely tested. As a result, a hull designed from first principles may either appear to be overbuilt – in which case it is going to withstand even that '0.5 per cent of the time' peak load – or else may appear to defy the odds and remain afloat when it is lighter than any other, which could be down to pure chance.

Once a loading situation has been decided on, we have to select materials and component geometries sufficient to achieve the strength and stiffness required. At this point, it is meaningless to select a material purely because it is stronger than another product, because it is of course possible to use more of – or a higher density of – a given material, as long as the design criteria are met. It is possible to build two boats, each capable of carrying identical loads yet built of materials of vastly differing strengths: the question about which weighs more, a ton of feathers or a ton of lead, springs to mind.

The hull shell laminate has, first, to have sufficient bending strength. This is primarily a function of the skins, but their separation – the core thickness – is a significant factor. Second, it also has to be stiff enough. This is somewhat more subjective, because at this stage we are not talking about overall stiffness and hence forestay tension/doors opening and closing, but local panel stiffness. In the case of a deck, the requirement is more obvious, since a 'spongy' feeling deck is definitely harmful – to crew morale, if nothing else. Once again, it is only the core thickness that we are worried about here. Finally, it has to have sufficient shear strength: this is a function of the core material – type and density – and also of its thickness. If therefore we have decided on a thickness to meet the first two criteria, we then have only two parameters to play with – material type and density.

**'There's no point spending heavily on wonder materials if the design will be heavily cost constrained elsewhere'**

**2. Secondary structural design criteria.** Life is never so simple. Although we may have selected a core thickness to meet bending and stiffness requirements, and then chosen the type and density to be strong enough in shear, there are further structural criteria which must be considered.

A good example is skin denting resistance. Until recently it would have been possible to follow the letter of the ABS rule in meeting strength and stiffness requirements and choose a thick core with very thin skins and only need a low density.

Unfortunately, the inescapable corollary of this design route would be a hull shell which was as sensitive to bruising as a surfboard. In the case of a very thin-skinned structure, therefore, it may be necessary to choose a higher core density – at least for the layer immediately below the outside skin surface.

A similar situation might arise on an unsupported side-deck. Decks are primarily designed as stiffness-critical structures and on a very lightweight boat a large-celled honeycomb core may meet most of the requirements. If, however, the skins are thin and there is a high in-plane compression load – perhaps caused by rigging tension – it is possible that the panel may fail due to skin dimpling caused by unsupported skins buckling in the short free span between cell walls. Crushing strength is an obvious requirement in the way of high local loads, such as through hull or deck fittings – keel bolts or traveller tracks.

The increasing number of track-type race boats that are being driven very hard offshore has also given rise to another consideration – until now normally associated with high speed powerboat design – that of fatigue and slamming loads. To this end a core may be selected (after meeting the other criteria) on the grounds of its dynamic shock absorbing characteristics or rejected on the grounds of too high a through plane stiffness (transferring very high loads immediately to the inside skin).

**3. Price.** Although an obvious category, it is not always included in the design process as quantifiable, which is really a mistake. Most engineers would agree that although there are areas of a design which can be ranked in order of importance, and hence perhaps safety factor applied in design, those which lie on the same level would ideally 'all fail at once' if the design loads ▶

were exceeded. This would suggest that unnecessary material was not being carried and equally that one area was not dramatically weaker and letting the others down.

The same is true of pricing. If the two main parameters in a design are to be cost and weight (to meet a minimum given strength) then the weight savings gained by using more expensive materials need to be quantified and levels set throughout the structure. One would presumably spend more to save a kilo at the top of the mast than in the keel floors, but it would be inappropriate to use an expensive core for little gain right next to a skin which could be upgraded to give the same gain more cheaply.

An overall idea of how the cores perform relative to one another cost wise is therefore very important, and a medium-budget boat may therefore be able to benefit from a high-tech deck core, medium-cost topsides and budget bottomshell construction.

**4. Processing.** Various factors are at sway in this area. Not only must the various materials and processing techniques be compatible, but also choices have to be made on the grounds of practicality. Quite apart from technical considerations like material compatibility, processing temperatures and pressures considerations will come into play, such as lead time, number of materials to be held in stock, and even local storage conditions and climate.

The important technical considerations all relate to the actual construction techniques. A core with a low crushing strength would be useless in an autoclave cure, and one with a low processing temperature limit could not be used with a higher-temperature prepreg. Likewise, a core that was chemically sensitive to components of the bonding agent would have to be rejected.

Having explored the parameters which affect the engineers' selection of core material for a particular end use, it is important to examine what data is available and how that data may be derived. All core manufacturers publish data pertaining to their products. By and large these manufacturers are active in many industries, and the marine market may represent only a small part of their overall sales.

Most other users of structural core materials will have more tightly regulated controls on structural matters within their sphere. As a result, although the marine industry is sometimes receiving material that was not classified for aerospace use, it is normally well tested and its properties documented. As a result data sheets showing density, shear strength, compressive and shear modulus and so on, are readily available. These numbers can usually be used with some confidence, although the normal warnings to beware of – comparing like with like – apply.

Unfortunately, there are some problems with this non-marine focussed situation.

**1.** Manufacturers and their representatives can sometimes be seen to be pushing 'advantages' which – though real – are not actually advantages at all to the marine user.

## 'strong material is not necessary to build a strong product'

**2.** Quoted properties can be derived from tests which do not reflect the end use to which the boatbuilder puts the material.

In order to illustrate the first point, we will have to briefly examine testing and its application to core materials.

The most common way of establishing the behaviour of structural cores is to perform a simple four-point bending test, although there are other techniques available. The bend test for sandwich composites is a useful one, because within very similar testing envelopes quite a large amount of data can be obtained: not just about how the core is likely to behave when used in a boat, but also about how the sandwich behaves as a whole – its stiffness and also the maximum bending moment that can be carried before failure of the skins occurs.

This test is often misinterpreted because of the changed emphasis of the test when the geometry of the test rig is altered. The specimen is usually about 100 mm wide and will vary in length, depending on whether you wish to learn about the core properties or the bending/stiffness characteristics of the beam.

If core shear strength or shear stiffness data is required, the supports for the beam are brought relatively close to one another, similar to a guillotine used to shear metal. Alternatively, if bending strength or bending stiffness information is required the supports are moved further apart, which effectively loads the skins of the sandwich. Here, the thickness of the core rather than its density is of importance.

Careless use of such data could, however, be used to show that a core with high-shear stiffness will produce a sandwich laminate of higher-bending stiffness than one cored with low-shear stiffness material. In boat structures, shear stiffness of a laminate is not generally considered to be significant when compared to bending stiffness. Thus, although the data presented may be correct, it has little relevance to the marine industry and could prove to be misleading to the casual reader.

In summary, it can be said that all cores have individual limitations which can fall into any one of the criteria considered. Recently highlighted problems in using some foam cores cannot be blamed on the cores themselves, as their properties are well known. Equally, claims that a particular core is best can be made only against the background of one particular end use and should be qualified accordingly. Once again, it must be reiterated that a strong material is not necessary to build a strong product. Once a level of strength is defined the material can be chosen using all of the above parameters and the quantity required to achieve the level determined.

As engineers it is our job to make sure we know as much as possible about all aspects: physical properties, price, handling and so on of as many core materials as possible – and then with the client, we can decide which aspects are most important.

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