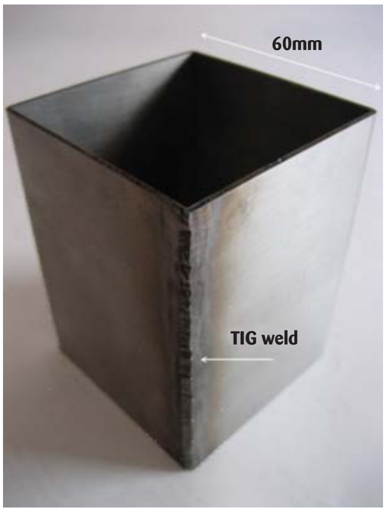
Stainless steel

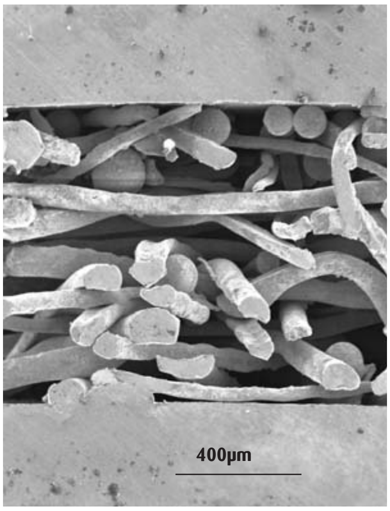
Sandwich materials first rose to industrial prominence during the second world war when, owing to an aluminium shortage, balsa wood sandwiched between two sheets of plywood was used to construct the fuselage of Mosquito bombers.

Since then a wide variety of hybrid materials have been developed, including all-metal sandwich materials of which Fibrecore is the most recent example. This high stiffness metallic material was designed as a drop-in sheet metal replacement. Fabricated entirely from stainless steel with thin faceplates and a novel melt spun fibre core, it has an overall thickness of around 2mm and an areal density below that of a titanium sheet of the same thickness. Assembled at room temperature, prior to high temperature vacuum diffusion bonding, it can be machined, formed and welded using conventional metal fabrication techniques.

The sandwich material was developed at Cambridge University's Gordon Laboratory, in collaboration with Fibretech and the Defence Science and Technology Laboratory in the UK. Its low cost, high structural efficiency and good energy absorption characteristics make it attractive for a range of commercial and defence applications. The thermal and acoustic properties are also potentially useful for filtration, heat exchange, structural cladding, fire protection, vibrational damping and noise attenuation applications.

Below left: Welded hollow box section.
Below right: Cross section of sandwich structure





Construction

Manufacture occurs in two stages. The standard product is prepared by evenly depositing a 1.2mm thick layer of melt spun 304 stainless steel fibres onto a 0.4mm thick sheet of 304 stainless steel. A second sheet of 304 is placed on top of the metallic fibre layer and the resulting assembly is diffusion bonded under vacuum at 1150–1250°C for 30-90 minutes. The process is very flexible and can easily be modified to produce sandwich sheets of up to 500 x 1500mm in size from a number of stainless steel grades. Flat and curved multi-layered structures, in a range of thicknesses, can also be produced. A continuous production process design study has also been undertaken in anticipation of a significant rise in demand for low cost, lightweight materials over the next three years.

Core architecture and properties

With core densities in the range of 10–25%, the Fibrecore is typically manufactured using 5mm-long, 70µm-diameter stainless steel fibres produced by a melt overflow process. Melt overflow is a highly efficient and cost-effective method of manufacturing metallic fibres with diameters of 50–500µm and lengths of 1.5–50mm. The core architecture – particularly the fibre orientation and segment length distributions – is controlled via the initial fibre aspect ratio and consolidation conditions during manufacture. Tailored orientation distributions can be produced and models are available for calculating various thermal, electrical, elastic and fluid permeation characteristics.

Stiffness

Sandwich panels with low density cores are known to exhibit high bending stiffness. For the same areal density, the beam stiffness of Fibrecore, with a thickness of 2mm and a core density of 10%, is about 300% higher than titanium and nearly 800% higher

sandwich

The desire for cost effective, lightweight, crash-resistant materials continues to drive the use of conventional materials in novel ways. Dr Peter Brown of the Defence Science and Technology Laboratory in Wiltshire, UK, discusses Fibrecore, an entirely metallic, diffusion bonded, sandwich sheet material.

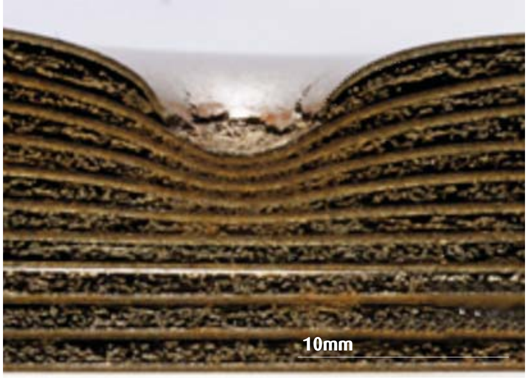
than steel. For the same sheet thickness, its beam stiffness is 40% higher than titanium and more than 200% higher than aluminium. Perhaps most importantly, for the same beam stiffness, the materials is 50% lighter than conventional steel sheet.

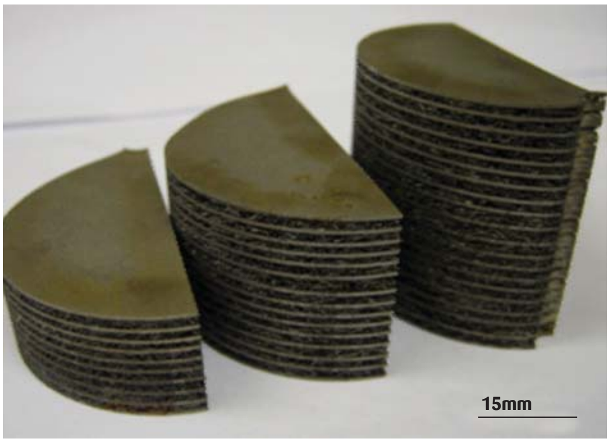
Fabrication

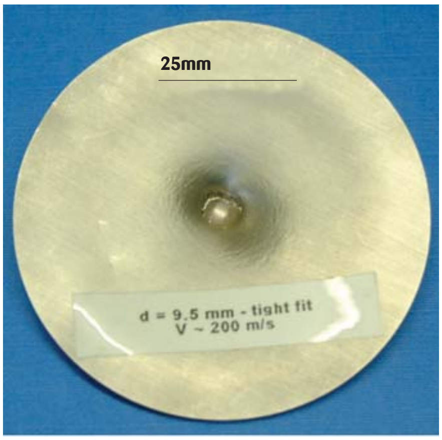
Owing to its entirely metallic construction, Fibrecore can be spot and tunsten inert gas welded without difficulty. It can also be milled, drilled and cut using conventional sheet metal fabrication techniques. Drawing, folding and pressing operations are also possible provided excessive deformation is avoided. Where more complex, deeply-drawn shapes are required, incremental sheet forming, which employs a travelling indenter, should be considered. The highly localised shear deformations associated with this process lead to a more uniform strain distribution, the avoidance of necking, reduced core crushing and the production of wrinkle-free components.

Impact

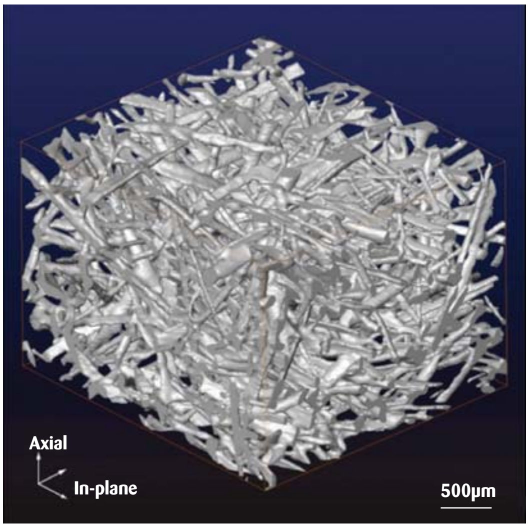
With good energy absorption characteristics, the panels can withstand a 70 joules (J) impact from a 9.5mm diameter steel ball bearing at 200m/s. When multi-layered, even higher levels of performance are shown – with 20-layers, the material is capable of resisting impacts of up to 1,000J. When used in conjunction with disruptive layer methods, multi-layer technology also provide effective protection against high-velocity ballistic projectiles.

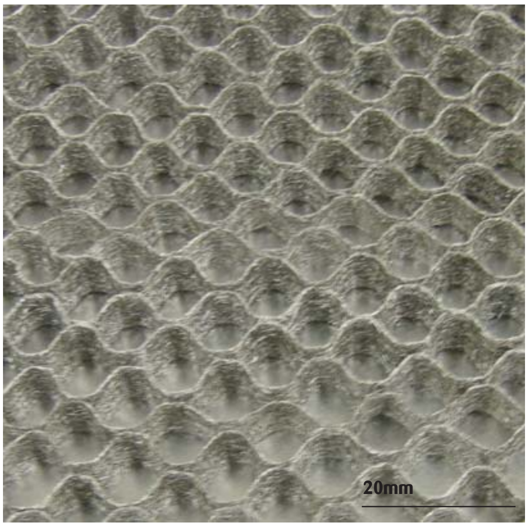






Top from left to right: Melt spun core fibres. Fibrecore preform prior to diffusion bonding. Response of a 10-layer panel to a 200 joules impact. Bottom far left: 10, 15 and 20-layer material. Left: Response of sheet to a 70 joules impact





Above: Simulated (top) and actual (below) impact reponse of sheet.
Above far right: Welded box section after compressive overload.
Right: Core architecture of sheet obtained using X-ray tomography.
Far right: Low-cost honeycomb core produced from 304 stainless steel melt spun fibres

Crushing

The main energy absorption mechanisms exhibited by Fibrecore are core crushing, core-faceplate delamination and plastic faceplate deformation, often in a concertina-like fashion. All three mechanisms have been observed during the compressive overload of welded box sections, which absorbed over 4kJ/kg during collapse.

Optimisation

Finite element (FE) simulations have been conducted to model both the static and impact loading response. The materials's' fibrous metallic core is currently being modelled as a transversely isotropic crushable foam – good qualitative agreement with experimental observations has been achieved. Recent innovations include the modelling of multi-layer materials and the use of core architecture data obtained by X-ray tomography. Such modelling can be used as a design tool to produce application-specific materials.

Applications

In addition to being light, strong, stiff and weldable, there are also good corrosion, impact, vibrational damping, acoustic attenuation and thermal insulation properties. Fibrecore is currently being evaluated for automotive and defence applications, including vehicle body panels, exhaust system noise reduction, low cost filters and lightweight physical protection. Other areas being explored are large area thermal, acoustic, decorative and fireproof cladding, lightweight marine decking, aerospace fuselage structures, low cost heat exchangers, crash barriers, automotive crumple zones and volatile chemical storage container applications.

Future

Both single and multi-layer versions have been developed to the point where they can now be routinely produced using a semi-industrial scale batch process. Future work will focus on developing a wider range of product forms, including ultra-high strength, curved and honeycomb fibre core variants, with the potential for a continuous production plant being commissioned in due course. ●

Author's details

Lee Marston, Technology Manager of Fibretech. E-mail: lee.marston@fibretech.com or visit: www.fibretech.com. James Dean of Cambridge University, UK. E-mail: jd362@cam.ac.uk, website: www.msm.cam.ac.uk/gordon. Co-authors – Dr Jin Chong Tan, Dr Athina Markaki and Prof Bill Clyne.