Lightweight Sandwich Structures for Vehicles and Vessels

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DE-LIGHT Transport

Sandwich materials, consisting of two thin facings separated by a low density core, can be used to produce structures that are both light and stiff. They also offer opportunities for parts reduction through design integration, improved surface finish and lower assembly and outfitting costs. DE-LIGHT Transport aimed to further promote the use of sandwich materials by developing key technologies to support the practical realisation of robust sandwich designs. Specifically, this included:

• The development of a multi-material sandwich design tool. Previous work has often focussed on a particular type of sandwich construction (e.g. laser-welded steel or composite). This has tended to yield niche results with limited applicability. DE-LIGHT Transport has implemented a more generic design approach that allows the evaluation and optimisation of a wide range of material and structural mixes according to the requirements of a given application.

• Strategies for joining, assembly and outfitting – the bringing together and integration of separate sandwich panels and/or sub-components to produce finished structures. In particular, modular approaches for the off-line production of sandwich assemblies to exploit economies of scale have been developed.

• Testing and validation procedures – to provide accurate and reliable methods of determining fitness for purpose.

The above technologies were demonstrated within the project through the design and manufacturing of six prototype structures. These included deck and deckhouse structures for ships, a rail vehicle cab, and a freight container. Risk-based design principles were applied throughout to ensure that the new designs comply with existing regulatory frameworks.

The DE-LIGHT Transport project ran from November 2006 to January 2010.
Multi-material sandwich design tool

Problem addressed
The design and optimisation of sandwich structures, particularly those employing non-isotropic facings and cores, can be a very complex and time-consuming process. This is because of the large number of parameters associated with the design, e.g. material selection, material orientation, facing and core thickness, core geometry, joining method, etc. These all play a critical role in determining the overall properties of a sandwich structure. Therefore tools are required to simplify the design process.

Progress in this area was made in two recent European projects – HYCOPROD and SANDWICH – in which two (separate) design tools were developed. Although both tools were able to perform several specific analyses relevant to sandwich design, neither covered a sufficiently broad range of design criteria to be universally useful. Thus, there was a need to integrate these two tools and further develop their capabilities to meet the requirements of the DE-LIGHT Transport case studies.

Results
Existing sandwich design tools that had been developed in previous European projects were analysed for their similarities and differences, and then compared against the requirements of the DE-LIGHT Transport application cases. In addition to the existing sandwich panel stiffness calculators, the DE-LIGHT Design Tool was extended to include a customisable material database, as well as new design and optimisation algorithms that broaden its scope.

It is envisaged that the tool will continue to evolve as an integral part of new research projects.

Material database
The DE-LIGHT Design Tool incorporates a material database. This was populated with test data generated during the project, data from previous projects, and data from open literature. The database is fully customisable with the facility to add new materials and material properties.

Design and optimisation algorithms
The DE-LIGHT Design Tool includes new algorithms for design and optimisation based on scientific results generated within the project. They have been implemented in a user-friendly way using an intuitive drag-and-drop interface.

The underlying theory behind the new algorithms has been published within the scientific community.

The client/server architecture of the tool allows it to be continuously updated with improved algorithms and new features. Throughout DE-LIGHT Transport, end-user feedback was used to enhance the tool.

Partnership
Aalto University Foundation, BALance Technology Consulting, NewRail, CMT, Riga Technical University, IHD, IFAM, Uljanik Shipyard, Meyer Werft, Damen Schelde Naval Shipbuilding, APC Composite

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Problem addressed
One of the barriers to the more widespread adoption of sandwich materials and structures is a lack of affordable production techniques. This is also the case for in-service aspects such as inspection, maintenance and repair.

As such, the use of sandwich materials in primary structures is currently rather limited. This limited application makes it difficult to exploit potential economies of scale.

Results
This aspect of the project defined a series of processes for achieving the cost-effective, reliable and flexible production of multi-material, lightweight sandwich modules. These processes were tested and validated, taking into account the relevant approval aspects. Furthermore, recommendations were made for best exploiting modular design and manufacturing principles, and for more efficient work sharing within the process chain. These recommendations were implemented within the six DE-LIGHT Transport case studies.

Multi-material panels
The investigation included the reinforcement of laser-welded steel sandwich panels with outer layers of fibre-reinforced polymer composite. This was found to be an effective means of improving fatigue performance, increasing bending stiffness, and reducing mass.

Joining techniques
A catalogue of new and established joining solutions for sandwich panels was developed. For selected solutions, detailed designs were prepared and test pieces manufactured.

Partnership
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Testing and validation procedures

Problem addressed
If advanced sandwich designs are to be adopted by the transport sectors, there is a need to review and, where necessary, develop and update test procedures to ensure that sandwich materials can be accurately and representatively characterised. The acceptance of advanced sandwich materials is heavily dependent upon the development of best practice testing techniques.

Results
The combined testing requirements of the six DE-LIGHT Transport application cases were identified and, where appropriate, opportunities for harmonisation were highlighted. These tests were then performed within three key areas:

• Quasi-static testing – stiffness and strength of sandwich materials, including joints, inserts and assemblies.

• Durability testing – corrosion, impact and other environmental effects.

• Fatigue testing – structural integrity over the life of the proposed application.

The best practice developed during these tests has been documented, and recommendations have been made to improve testing techniques.

Partnership
NewRail, CMT, Uljanik Shipyard, Meyer Werft, Damen Schelde Naval Shipbuilding, Ovidius University of Constanța, University of Zagreb, Bombardier Transportation, AP&M, IHD, APC Composite, Swerea SICOMP, IFAM, DNV, BALance Technology Consulting, Riga Technical University, Gdansk University of Technology, Aalto University Foundation

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Deck structures for car carriers

**Problem addressed**
RoRo / car carriers have numerous internal strength decks. The clearances between decks are fixed and defined by cargo requirements (i.e., the height of cars and trucks). Reducing the mass of deck structures is a very challenging task, but can result in significant benefits for the overall ship design due to the large number of decks. These benefits include a lowering of the centre of gravity, a more favourable trim condition, and better stability.

Within DE-LIGHT Transport, the design and manufacturing of lightweight fixed deck structures produced from both steel and composite sandwich structures was investigated.

**Results**
The overall result was the development of an optimised deck structure using DE-LIGHT Transport sandwich modules. Furthermore, it was shown that the technology can be accommodated within existing classification society rules.

The work included the design of the structure, the development of the manufacturing processes, a safety evaluation, and a study of the life cycle costs. Furthermore, prototype deck sections were manufactured and tested. The lightweight DE-LIGHT Transport structures were found to provide the following benefits: a deck mass reduction of up to 35%, a three week saving in shipbuilding time, a 20% reduction in deck production costs, improved stability, an increase in capacity of 200 cars, and reductions in fuel consumption, CO₂ emissions and life cycle costs.

**Partnership**
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Prototype undergoing long term testing
Problem addressed
This application case examined two aspects relating to new materials for balconies and decks in cruise ships:

1. The use of prefabricated balconies:
   • Modular design with pre-outfitting in workshops.
   • Standardised and reduced number of components.
   • Use of lightweight sandwich panels.
   • Cost reduction and improved quality.

2. The implementation of Thermally Modified Timber (TMT) for deck structures:
   • Ecological European wood in place of teak.
   • Installation by bonding.
   • Lower material costs and reduced lead time.

Results

• The properties of the wood and the sandwich panels were specified and tested.

• The manufacturing and assembly process was optimised – the best solution for the shipyard was identified.

• Physical prototypes were produced and fully documented.

• Tests for inspection, repair and maintenance were made.

• Life cycle cost calculations showed significant potential weight and cost savings.

• The implementation of the research results has already started. 52 prefabricated balconies have been installed on the ship Celebrity ECLIPSE.

Partnership
Meyer Werft, DNV, IFAM, Balance Technology Consulting, IHD

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Superstructures for offshore patrol vessels

Problem addressed
On the majority of offshore patrol vessels developed today, steel is used as the primary construction material. In order to meet the stability and weight requirements, very thin plates are used, which tend to result in welding distortions. These welding distortions lead to the so-called ‘hungry horse’ look, and an increased radar cross section. To avoid welding distortions, specialised welding techniques, fairing and stretching are required, which is expensive and labour intensive. Alternative structural materials such as composites are not widely used due to their perceived incompatibility with traditional shipbuilding processes, and issues such as joining and fire safety.

Results
Laser welded steel sandwich structures offer benefits such as high surface flatness and shorter lead-times. Carbon fibre sandwich structures offer great potential for weight saving. This case study aimed to develop a modular methodology for sandwich-panelled structures in a shipyard environment. This included joining technologies, the integration of the sandwich panels within the overall ship structure, and the application of class approval principles with respect to fire safety.

A comparison was made between steel and composite sandwich structures and an assembly process was developed in which deviations could be implemented at a later stage of the design and production process. Furthermore, a risk based design methodology was applied, aiming for a composite structure meeting IMO regulations. A fully adhesively bonded superstructure to the steel hull was developed, realising an approach based on more than 20 years of experience with DNV approval principles. Finally, a prototype was produced demonstrating the modularity and applicability of sandwich construction in a steel shipyard environment.

Partnership
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**Problem addressed**

The rail industry needs lightweight materials and structures for vehicles in order to meet the challenges it faces in terms of energy efficiency. Lightweighting also brings reductions in vehicle operating costs, and lighter vehicles cause less damage to track, thereby reducing levels of infrastructure renewal.

Conventional rail vehicle cab structures are typically based on welded steel assemblies and are therefore relatively heavy. Furthermore, current cab designs tend to be very complex, high part count assemblies with fragmented material usage. This is because they must meet a wide range of demands including proof loadings, crashworthiness, missile protection, aerodynamics and insulation. Assembly costs are high, and there is little in the way of functional integration.

**Results**

The lightweight, crashworthy cab that was developed in DE-LIGHT Transport contained a number of innovations compared to more traditional designs. These included a modular construction, an energy absorbing nose section, lightweight concepts for the main crash energy absorbing devices, and the use of an integrated composite sandwich for the main cab structure.

A full-scale prototype of the lightweight crashworthy cab was manufactured (below right). This realised significant savings in both mass (up to 50% according to preliminary estimates) and part count (up to 40%). The integrated modular design of the DE-LIGHT Transport cab also significantly reduces outfitting and assembly costs, leading to overall cost savings.

**Partnership**

Bombardier Transportation, NewRail, AP&M.

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Life cycle costing

Problem addressed
Under today’s cost pressures and society’s increasing environmental awareness, the transport sectors are facing the challenge of significantly reducing their fuel consumption.

Lightweight design solutions can provide one contribution to the reduction of the fuel consumption associated with the transportation of a given payload. Sandwich structures may also provide other whole life cost savings such as reduced maintenance and repair.

Life cycle evaluations can be used to support the introduction of lightweight materials by quantifying their whole life benefits under a range of operational scenarios.

Results
Two life cycle cost (LCC) models were developed within DE-LIGHT Transport, one for ships and another for trucks. These models are able to estimate the life cycle cost benefits associated with the DE-LIGHT Transport innovations. This includes:

• Identifying the most effective technologies and approaches for reducing life cycle costs.
• Calculating the fuel cost savings associated with lightweighting.
• Forecasting the expected maintenance and repair costs over the life of the vehicle or vessel.
• Estimating the break-even point associated with the investment in the lightweight innovation.

Partnership
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Variation of investment and fuel costs for a Ro-Ro vessel equipped with different types of car deck

Weight reduction and fuel cost savings for different balcony materials on a cruise vessel