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Lightweight Design

Lightweight design can be defined as "the science and the art of making things—-parts, products, structures—as light as possible, within constraints".

From: Materials Experience, 2014

Related terms:

Energy Engineering, Struts, Additive Manufacturing, Internet of Things, Compressive Strength

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Lightweight Materials, Lightweight Design?

Erik Tempelman, in Materials Experience, 2014

Abstract

Lightweight design is often associated with the application of lightweight materials, but that is only part of the story. In fact, if one would reduce the one to the other, the most probable outcome will be just a very modest weight saving, gained at a very high price. This chapter aims to tell the full story of how lightweight materials fit within lightweight design, presented in the form of seven design rules. In doing so, it reveals several surprising materials that designers can use to make things – parts, products, structures – lighter, and shows why lightweight design matters, more now than ever before.

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Polymer Matrix Composites: Applications

Luke P. Djukic, ... Manudha T. Herath, in Comprehensive Composite Materials II, 2018

3.16.2.1 Lightweight

Lightweight design and construction is a major benefit for transportation tanks. In many countries, regulations impose a limit on the gross mass of road vehicles. The gross mass of the vehicle includes the tank, its cargo, the trailer, and prime mover. These regulations also impose a limit on the forces that individual axles can exert on the road through the contact wheels, with the sum of all axles adding to the gross mass of the complete vehicle. If the mass of the tank, trailer or prime mover can be reduced, then additional cargo can be transported, whilst keeping the complete vehicle at or below the gross mass limit, provided that the mass reduction is accompanied by an increase in the volume of the tank. Ang-Olsen and Schroeer[1] discussed bulk liquid transport tankers and identified that lower mass tanks allow additional payload in a single transport run when tankers are operated at maximum gross mass. Gao *et al.*[2] stated that when tare mass is reduced, the tank payload capacity should increase, to increase the ratio of payload to gross mass. The required volume of the tank to achieve the maximum gross mass of the vehicle is a function of the density of the liquid being transported. Tare mass reduction and consequent payload increase allows transport operators to reduce the number of transport vehicles that are required to perform their operations when moving large annual volumes of product. Lower vehicle tare mass also results in lower fuel consumption per unit volume of cargo transported.

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Design and Analysis of Composite Structures

Peter Middendorf, ... Karin Birkefeld, in Comprehensive Composite Materials II, 2018

8.3.2.1 CFRP-Based Manipulators

With intelligent lightweight design, further improvement of manipulators is realized. The use of CFRP leads to considerable weight savings in comparison to metal design. Furthermore, the way of producing a CFRP component strongly influences their performance. Braided structures offer advantages that in particular come into effect when looking at a manipulator. First, the interweaving of fibers increases the impact resistance and damage tolerance. Second, fiber properties can be adapted continuously by changing the interweaving angle of fibers and the amount of axial reinforcement during the braiding process. Furthermore, the braid will adapt to different cross sections automatically. Hence complex geometries, tailored for different load cases and package situations can be designed.[1]

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Design and material utilization

Geoffrey Davies, in Materials for Automobile Bodies (Second Edition), 2012

Lightweight design and safety – with CFRP, lighter also means safer

In addition to lightweight design, passenger safety also played a major role in the development of the LifeDrive concept. The current impact stipulations for a vehicle body are extremely stringent and a wide range of different crash scenarios have to be taken into account. Generally speaking, this presents development engineers with serious challenges, especially as far as the use of new materials is concerned. However, the combination of aluminum in the Drive module and the CFRP passenger cell in the Life module exceeded all expectations – even in the initial testing phase – and clearly showed that lightweight design and safety are not a contradiction in terms.

Lightweight design does not automatically mean 'unsafe' – quite the contrary, in fact: in some respects, the LifeDrive concept outperformed existing constructions in crash testing.Nils Borchers

Impressive rigidity, combined with its ability to absorb an enormous amount of energy, makes CFRP extremely damage-tolerant. Even at high impact speeds it displays barely any deformation. As in a Formula One cockpit, this exceptionally stiff m aterial provides an extremely strong survival space. Furthermore, the body remains intact in a front or rear-on impact, and the doors still open without a problem after a crash.

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Designing aircraft seats to fit the human body contour

Suzanne Hiemstra-van Mastrigt, ... Peter Vink, in DHM and Posturography, 2019

Abstract

To save fuel costs, lightweight designs and materials are preferred for aircraft interiors. One of the challenges for aircraft seats is to reduce weight without compromising passenger comfort, or perhaps even while increasing comfort. This case study describes three different projects on lightweight designs for aircraft seats, using three-dimensional (3D) scanning methods (Franz, Kamp, Durt, Kilincsoy, Bubb, & Vink, 2011) to determine the ideal seat contour following the human body. The first project on upright sitting in an economy aircraft seat (Hiemstra-van Mastrigt, 2015) set out to collect imprints of the human body in a vacuum mattress by using a handheld 3D scanner to scan the body imprints and obtain a 3D surface. Subsequently, the different scans were superimposed in such a way that differences between the scans were minimized. Based on this “ideal curvature,” an adjustable seat pan concept was developed (Kuday, 2018). A similar 3D scanning method was applied in two other projects: first, developing a prototype for passengers sleeping sideways in a premium economy class aircraft seat (Lam et al., 2014) and, second, a human contour-based business class seating concept (Smulders et al., 2016). This case study concludes with advantages and recommendations for applying 3D scanning in similar projects.

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Lightweight design and crash analysis of composites

S. Boria, in Lightweight Composite Structures in Transport, 2016

13.7 Conclusions

This chapter describes efforts made in the lightweight design and crash analysis of specific CFRP structures. In particular, simple geometries, such as truncated cones, and a more complex one which represents the frontal impact attenuator for a Formula SAE racing car were investigated. The evaluation of the energy absorption capacity varying some geometrical parameters and test conditions was done. Specimens were subjected to static and dynamic axial loading, using well-proven testing machines. The tests carried out showed the two crushing forms typical of the first failure mode of thin-walled composite structures, characterized by the best energy absorption capacity and by a progressive and controlled deformation. No difference in deformation was observed between equal geometries subjected to static and dynamic loading. For the conical structures a remarkable loss in the energy absorption capacity, increasing the load speed, was noted; such observation cannot be said for the impact attenuator, for which a very similar behavior was observed. For all the specimens a comparison with numerical modeling was done, in terms of both micro- and macromechanical models. In both cases the FE models were able to reproduce sufficiently well the crushing phenomena, despite the complexity and heterogeneity of the CFRP material used.

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Online and real-time damage calculation in automotive transmissions Application to remaining service life estimation

S. Foulard, ... M. Ichchou, in International Gear Conference 2014: 26th–28th August 2014, Lyon, 2014

5 CONCLUSION

In this paper, an original approach to introduce lightweight design in automotive transmissions based on the implementation of an online and real-time damage monitoring system in series production cars has been presented. The minimal requirements in terms of signal nature, calculation step time, load classification and consideration of dynamic events have been introduced. This helps also to define the performance specifications of the torque sensing method, which has to be employed. However, further investigations have to be done in order to develop a way to take into consideration the damage impact of the shift operations because of, for example, the difficulty to measure the transmitted torque during clutch slip phases in a real car. On the other hand, a global error accumulation due to the damage evaluation process (signals, step time, etc.), torque sensing (once developed) and SN-curves (standardly developed for the 99%-ile in the automotive industry) will have to be quantitatively determined in order to clearly qualify the accuracy of the proposed damage calculation.

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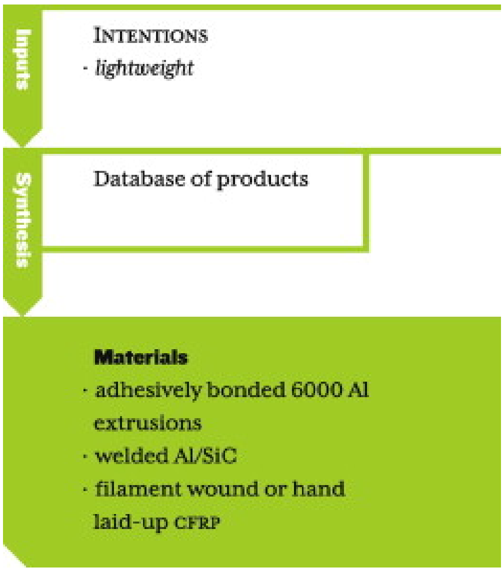
Material Selection

Michael Ashby, Kara Johnson, in Materials and Design (Third Edition), 2014

Material Selection – Synthesis

What can be learnt from synthesis (7.13)? The intention here is lightweight design. Where else do you find lightweight space frames? Car manufacturers, today, strive for light weight, and achieve it by building the car round a light, stiff space frame. Design for backpacking has, as one of its primary priorities, low weight: backpacks, tents, mountain climbing, and rescue equipment all have lightweight frames, here seeking strength rather than stiffness. And weight carries heavy penalties in other sports: the design of the frames of bicycles and of snowshoes is guided by minimizing mass.



7.13. **Selection by Synthesis** *Here we seek products that contain eight weight space frames, enquiring for the material and process by which they are made.*

A survey of materials and processes used in these products can suggest options for the desk. Both Audi and Lotus use extruded 6000 series aluminum, welded or adhesively bonded, and riveted, to create light space frames for cars. Backpacks and snowshoes, too, use 6000 series aluminum tubing, bent, welded, and finished by powder coating. Bicycle frames have been made of many different materials; several lightweight models use tubing made of the 6000/7000 series aluminum or of aluminum matrix composites. High performance backpacks and bicycles are made of carbon fiber-reinforced polyester or epoxy, either as tubing (but this is inefficient) or as a shell made, usually, by hand lay-up of woven prepreg. None use magnesium.

The first three of these are mass-produced products that command substantial market; they boost confidence that 6000 series aluminum holds no unpleasant surprises, and point to ways in which they can be joined (welding and adhesives) and finished (powder coated). This would be the safe choice – one already used in other, similar, designs. The small additional weight saving offered by the aluminum matrix composites does not justify its cost.

But could there be a more radical solution? cfrp bicycles use lay-up methods to create elegant, doubly-curved shapes; chairs exist that do the same. A high-end desk could be made in a similar way (7.14), molding-in attachment points for drawers and other fixtures as they are on the bicycle. That level of sophistication may not be justified here. But the lightness and stiffness of polymer-matrix composites is an attraction. Pultrusion is a relatively low-cost way of making high stiffness hollow sections of composites. These can be adhesively bonded using cast aluminum nodes at the corners, a technique used in some cfrp bicycles, to form a frame. There is potential here for major weight savings, coupled with novel visual appearance (black cfrp pultrusions with polished aluminum connections) that might be manipulated to give perceptions of advance precision engineering.

7.14. **Mobile Office Furniture** *With carbon fiber/epoxy composites, a stiff, light table can be formed.*

> Read full chapter

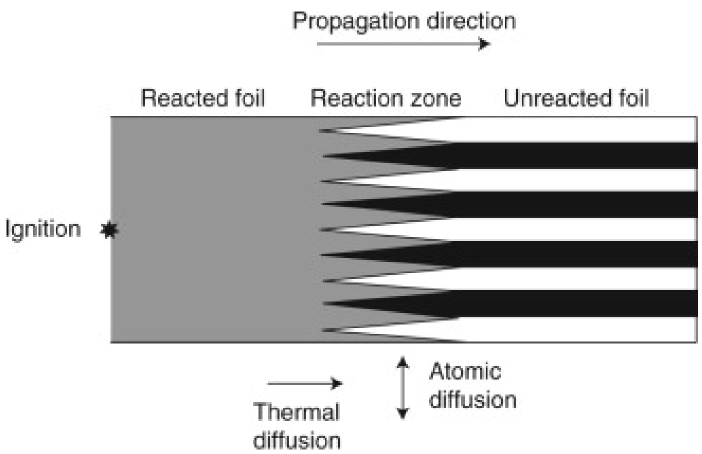
Joining lightweight materials using reactive nanofoils

X. Sun, in Failure Mechanisms of Advanced Welding Processes, 2010

11.1 Introduction

Advanced joining technology remains the key enabler for original equipment manufacturers to implement new materials for lightweight designs. Currently, fusion welding, resistance spot welding and adhesive bonding are the main joining technologies being used in the automotive production environment. While proven to be reliable in joining conventional materials, these methods present different challenges in joining similar and dissimilar advanced lightweight materials such as advanced high strength steel (AHSS), aluminum and magnesium. For example, the high heat input of fusion welding tends to destroy the designed microstructures of AHSS, rendering less than desirable joint properties and performance.

In this chapter, we present the performance data of an alternative bonding technology, namely, reactive NanoFoil® bonding, for joining automotive related lightweight materials. NanoFoil® is a multi-layer foil typically fabricated through the growth of thousands of nano-scale layers of two or more materials by vapor deposition.[1–3] Initiated by an energy impulse, an exothermic reaction occurs in which the like-like bonds of the atoms of each layer in the foil are exchanged for the more stable unlike bonds between atoms from neighboring layers driven by a reduction in the atomic bond energy. As the atoms of each layer mix, heat is generated, creating a self-sustaining reaction traveling along the length of the foil, see Fig. 11.1. Joining applications using this technique can include and range to the following materials and their combinations: steel, aluminum, magnesium and titanium.[1–3] In this chapter, we focus on the bond strength and failure mode evaluations of nanofoil bonded steel, aluminum and magnesium. In addition, a bond strength comparison with conventional structural adhesive will also be presented.



11.1. Schematic illustration of the NanoFoil reaction upon ignition.[1]

This type of self-propagating high-temperature synthesis (SHS) process was first reported by Russian scientists in the 1960s in Ti and B powder compacts.[4] It was found that the formation of TiB_2 from Ti and B powders produced heat fast enough to propagate across the powder compact. The process was later explored in joining materials and in near-net shape production of hard materials. However, since the characteristic diffusion distance for achieving full particle mixing is controlled by particle size and voids between powder particles, fully self-driven synthesis of powders was often difficult to achieve.

In order to control the diffusion distance between different reactants, fully dense multilayer nanofoils can now be fabricated through modern thin film deposition techniques. The individual layers in a reactive foil are usually on the scale of tens of nanometers and the total number of layers for the nanofoil can be controlled during fabrication, allowing significant control over the heat generation properties of the foil.[1–3] As such, reactive multilayer nanofoils can be used as an accurate, localized and self-propagating heat source to melt solder or braze layers in bonding different materials without compromising the properties/integrities of the base metal.

Because reactive NanoFoil® joining is a new and emerging joining technology, bond strength and failure modes in comparison with the conventional joining techniques need to be established. This information, together with the cost analyses and cycle time studies, will provide designers and manufacturing engineers with the necessary input to determine the feasibility of further applying this emerging technology in a production environment.[5]

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Developments in hybrid laser-arc welding technology

A. Gumenyuk, M. Rethmeier, in Handbook of Laser Welding Technologies, 2013

19.3 Examples of applications

The shipbuilding industry was a pioneer in the application of laser hybrid welding. Demand for new ships of lightweight design required the application of thinner steel sheets for their construction. This resulted in much higher levels of welding deformation and consequently in a high amount of rework in the pre-production stage. The main requirement for the introduction of a new welding technology was to significantly decrease welding distortions occurring during the manufacture of the stiffened panels, which require immense effort straightening procedures, as well as high costs (Roland and Lembeck, 2001). At the same time, the new welding technology needed to provide an appropriate quality at gap tolerances typical for the 20 m long sections. Laser hybrid welding provided the best prerequisites to fulfil these requirements, owing to its three times lower heat input compared to conventional arc welding and to its ability to bridge gaps of up to 1 mm in the thickness range relevant to shipbuilding. As a result of the substitution of laser hybrid welding for the conventional SAW in the production of stiffened steel panels at Meyer Werft in 2001, the productivity of this line was doubled and the amount of necessary straightening work reduced by 60%. Low levels of weld distortion allowed the manufacturers to increase the panel size from 10 m × 10 m to 20 m × 20 m. This resulted in the complete reorganisation of the production line, with four 12 kW CO_2 lasers executing all welding operations in stiffened panel manufacture. Today 20 m × 20 m large panels can be welded in 6 hours and a total length of 3 km of laser hybrid welds is produced per day. The total length of laser-hybrid welds in the construction of a 300 m long cruise ship is estimated to be about 400 km. The first generation of laser hybrid equipment used 12 kW CO_2 lasers in combination with a GMAW process. Recently the company purchased two 10 kW disk lasers, which will be integrated into the new production line for manufacturing parts of sections. The flexibility of the disk lasers due to the fibre delivery of the beam allows their use for more complex 3D welds, including welding in different positions.

Since 2008, a 10 kW fibre laser has been in use at the Fincantieri shipyard in Monfalcone, Italy. The 600 m long production line at Fincantieri was designed and realised by the company IMG (Seyffarth, 2010) for nearly deformation-free welding of 36 m long and 16 m wide panels with thicknesses in the range 4 mm to 20 mm. The production line also includes a highly precise milling machine for preparing the edges of the 16 m long steel sheets, directly before clamping them in the hydraulic fixture for welding. This provides a high level of precision with zero gap between the welded parts, minimising the risk of weld imperfections. For the first time an additional trailing tandem GMAW process was used in combination with laser hybrid welding, making a capping run. This combination enables the thickness of the welded sheets to be increased to up to 20 mm by preparing a Y-groove with a root face size adapted for 10 kW laser hybrid root run welding.

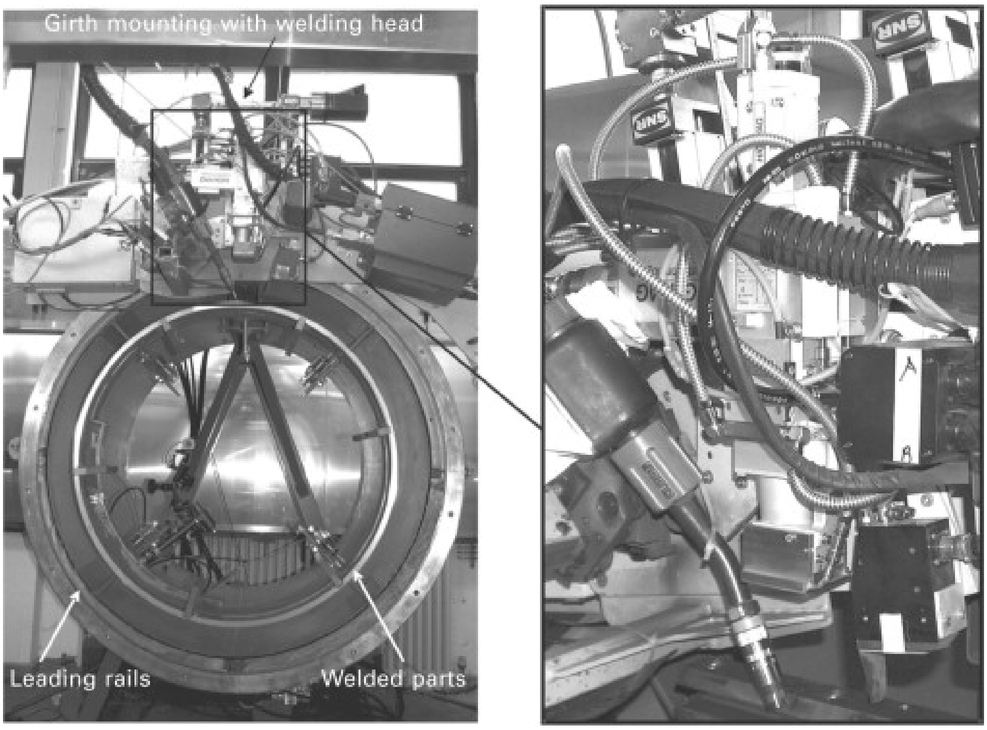
The compact design and high efficiency of high power fibre lasers provide the optimal conditions for their use in field pipeline construction. The first patented CO_2 laser system for offshore pipeline welding was tested in 1998. More recent solutions (Begg *et al.*, 2008; Harris and Norfolk, 2008; Neubert and Keitel, 2010) are based on the use of high power fibre or disk lasers in combination with one or several arc processes, which significantly contribute to the productivity and cost effectiveness of this welding technology. The idea of using lasers for pipeline welding is not a new one. Several research studies have been published since 2000 where the authors proposed CO_2 (Gainand *et al.*, 2000) or Nd:YAG (Fujinaga *et al.*, 2005) laser applications to establish this kind of welding technology for orbital pipeline welding. The weld thickness was mostly restricted to the value of 10 mm by producing either a single run or a root run for multi-run welding of line pipes of C-Mn steels. One reason for such a restriction was the power of the laser systems available at that time: either 12 kW CO_2 or 4.4 kW Nd:YAG. With the availability of high power solid-state laser systems like fibre and disk lasers, new possibilities have been opened up for establishing a single-run welding process for thicknesses up to 20 mm, as has recently been reported by Rethmeier *et al.* (2009).

The new laser tailored design of welded joints can result in significant savings on welding consumables. The higher welding speed of the laser beam welding process compared with conventional welding would result in a reduction of the production cycle time and in the long run in a reduction in the number of welding stations working in pipeline construction, while providing the same productivity as a conventional system. Direct comparison of three welding methods shows that the consumption of consumables can be reduced by a factor of five by the application of laser-hybrid welding to a 20 mm thick pipe compared with gas metal arc (GMA)-tandem welding, which is considered to be the most productive welding technology for pipelines, by a factor of ten compared with manual metal arc welding (MMAW), which is the most popular welding technology used today in pipeline construction. The difference is even more dramatic when studying the production time for one weld. For example, producing a complete weld will take about 1.5 min using laser hybrid welding, about 12 min using GMA-tandem welding and about 190 min using manual metal arc welding. At the same time, the energy consumption when using laser hybrid welding, despite the lower energy plug efficiency of modern solid-state lasers (approximately 30%), is comparable to that of GMA-tandem welding and an order of magnitude lower than that of manual metal arc welding. This is the reason why laser-hybrid welding can be considered a sustainable method of production, preserving resources and contributing to public health protection. On the other hand, in order to implement this technology in industry, it is necessary to meet the requirements of quality standards for the prevention of weld imperfections or at least for their reduction to an acceptable level, as well as for the achievement of high mechanical weld properties.

The possible applications of laser hybrid technology using high-power solid-state lasers for welding of transmission pipelines have been studied recently by several research teams. Different approaches have been suggested to suitably realise the orbital welding process for application in a field environment.

Taking advantage of the potential of modern lasers with output powers of 15 kW and more is an attractive option for welding of long distance transmission pipelines designed for high pressure operation and with a wall thickness of up to 42 mm. In this case, the economic impact of implementing the new welding technology becomes most remarkable, owing to the significant welding depths it is able to reach.

The first progress in this area was achieved by demonstration of the half orbital welding process, operating the fibre laser with an output power of 20 kW, for joining of pipe segments with a 36" outer diameter and 16 mm wall thickness. Orbital welding equipment, as shown in Fig. 19.2, has been used by the BAM Federal Institute for Materials Research and Testing in Berlin to perform these experiments. It was shown that the laboratory-developed welding process can fit the requirements of field pipeline welding, although some modification of the equipment has to be carried out to suit field conditions. In general, the laser hybrid process meets the tolerances originating from misalignment and irregularity of the pipelines.



19.2. Orbital welding equipment with laser arc hybrid weld head for large diameter pipes at BAM.

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