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Material Lightweighting Technologies

A short overview, main challenges, and a look into the future

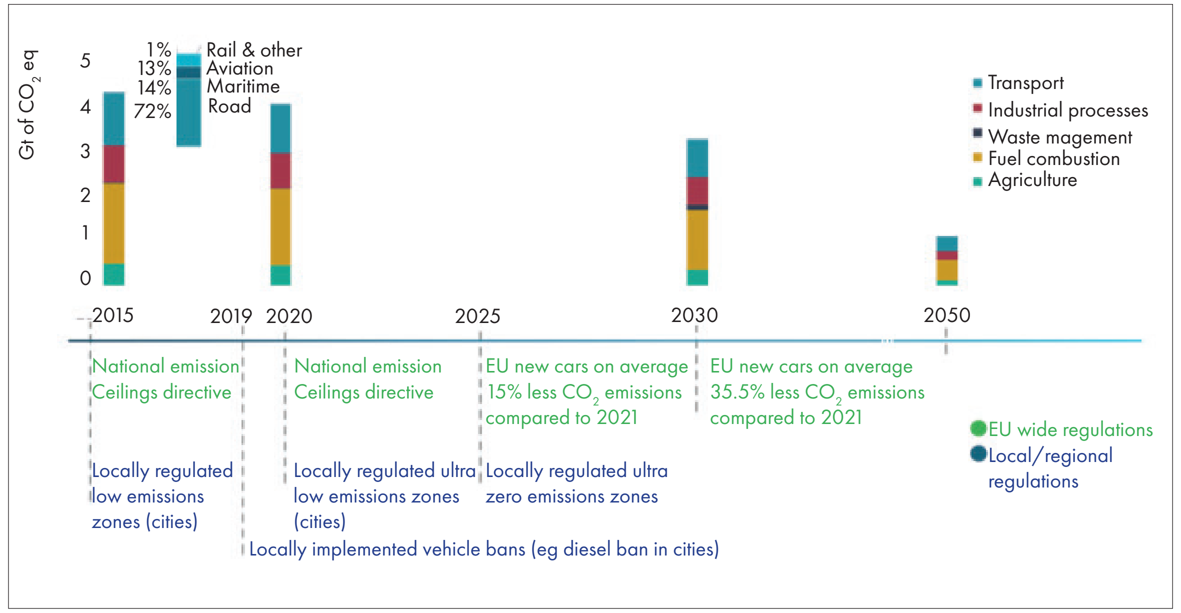
By Marcos Ierides & Johanna Reiland, BAX & Company

Improving the energy efficiency of transportation vehicles has been increasing in importance in the agendas of governments and industries alike. Their aim is to tackle the issue of transportation emissions, which have increased by 71% from 1990 to 2016, reaching a total of 8Gt of CO2, representing 25% of global CO2 emissions . This does not only present a challenge to be tackled, but a business opportunity as well. The market for lightweight materials is estimated to exceed 115 billion euros in 2019 , and continue growing with a CAGR of 5-10%. This market is primarily driven by the large volume of automotive applications – claiming close to 90% of the total lightweight materials market – followed by aviation.

Advanced materials are essential for improving fuel economy while maintaining safety and performance in transport applications. Advanced lightweight materials such as high-strength steels, aluminium and composites have been the subject of extensive research over the last few years, exhibiting weight reductions of >30% in the automotive industry, at a cost of ~€3/kg saved . Emerging material and manufacturing technologies have given rise to additional material solutions with significant light-weighting potential, such as polymers, ceramics and composites.

OVERVIEW

Such advanced materials are essentially a combination of different elements into a single material, which has significantly improved properties compared to the original raw materials. The main "families" of lightweight material technologies are metals, which include aluminium, steel, magnesium, and copper alloys; ceramics, including glass and crystalline ceramics; polymers, including fibre reinforced polymers (FRP) and to some extend organic materials such as wood.



In the spectrum of lightweight materials, aluminium alloys present an attractive and viable solution. Compared to steel, aluminium alloys have lower density, better thermal and electrical conductivity, lower strength to weight ratio, and are more ductile. Cost of components manufactured from lightweight aluminium alloys is 1.5 – 2 times higher than that of High Strength Steel (HSS), but up to 20 times lower compared to Carbon Fibre Reinforced Polymers (CFRP). Another quality of aluminium is that its properties remain essentially unchanged regardless of the process and use cycles, meaning it can be recycled virtually indefinitely. In fact, around 75% of all aluminium ever produced is still in use. Furthermore, recycling reduces the energy needed for primary aluminium production by 95% .

Over the last years, significant effort has been put in further increasing the lightweighting potential of aluminium, making use of new alloy compositions, and manufacturing and process parameters, aiming at increasing strength to weight ratio in order to reduce weight, and ensure safety and durability of applications.

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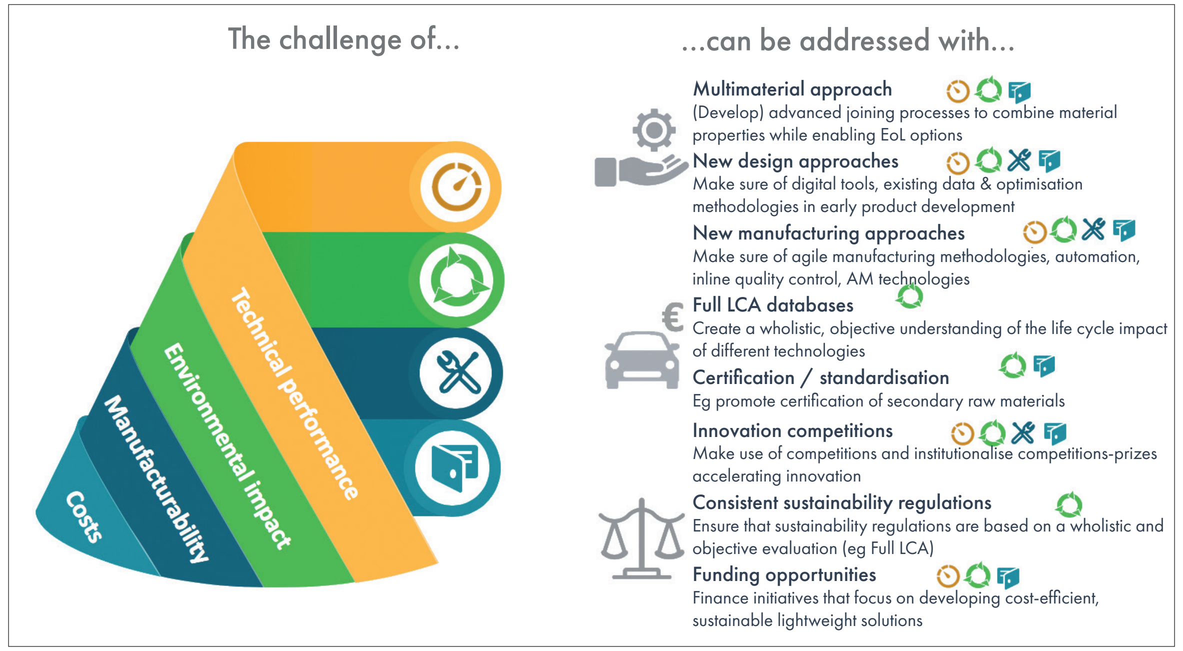

CURRENT CHALLENGES

With the transportation industry currently undergoing a radical transformation, new challenges arise, or overcoming existing ones becomes even more pressing. The main challenges to be addressed in the field of lightweighting for the next 10-15 years are:

■ Reducing the cost of lightweighting

The cost of the lightweight application (e.g. a module) includes its development, the raw materials, and its transformation into the final part. In the automotive industry, carmakers agree that a cost of lightweighting of around €3 per kg saved is acceptable for adopting new lightweighting technologies in high volume produced cars (>100,000 units/year). This makes the use of material technologies with very high lightweighting potential prohibitive, and restricts their use to high end, low volume vehicles with high profit margins.

REDUCING THE COST OF LIGHTWEIGHTING

■ Improving manufacturability of applications

Many of the – relatively – new materials that are being developed (e.g. FRP) often require a step change in how parts (or even vehicles) are designed and manufactured. This transition has not always been fast and smooth and in many cases, design and manufacturing engineers still work with old principles in mind. This often leads to high costs, high cycle times, and more importantly, not utilising the full potential of new materials. In aluminium sheet forming, challenges are often related to wrinkling and necking.

REDUCING ENVIRONMENTAL IMPACT

■ Reducing environmental impact

Although lightweight materials reduce energy consumption – and thus environmental impact – during the use phase of a vehicle, their lifecycle impact is not always well understood, and in some cases is worse than less light materials. This includes the raw materials, energy, and other resources used during the extraction and processing of raw materials, their manufacturing into components, logistics, as well as End-of-Life (EoL) treatment once the component has reached the end of its useful life. It is important to ensure that lightweight technologies have an overall lower negative impact over their lifecycle compared to conventional solutions.

■ Improving technical performance

This includes the crash performance, as well as durability and ageing behaviour. Several technologies with high lightweighitng potential and/or sustainable performance exist (e.g. natural fibres), but are still not suitable enough to be used in structural applications, limiting their use in specific semi- or non-structural parts. When it comes to aluminium, challenges are improving tensile strength, strain resistance, and sensitivity to stress corrosion cracking.

VIEW INTO THE FUTURE

Taking into consideration the above challenges, as well as the main drivers expected to influence the future of mobility, several new directions emerge. In the European lightweighting arena, most stakeholders agree that the main foci for the next decade are the following.

■ Develop and upscale technologies to enable multi-functionality and multi-material structures

New component designs make use of multiple materials, aiming to take advantage of the properties of each material for the needs of the specific application to reduce the overall weight. An example is the combination of CFRP, HSS and aluminium in the BMW 7 series body, while more elaborate solutions are being developed in R&D projects such as the ALLIANCE EU funded collaborative project3 in Europe, and the Multi Material Lightweight Vehicle in the US, funded by the US Department of Energy.

In addition to combining multiple materials, another lightweighting strategy is combining multiple functionalities. Such could be exterior parts with solar energy harvesting capabilities – incorporated in the Lightyear One prototype vehicle – interior parts with haptic interfaces, windshields incorporating displays, or CFRP components with energy storage capabilities . This combination of functionalities reduces the number of components necessary (e.g. storing energy in components reduces or eliminates the need for batteries).

Enabling multimaterial structures would require the development and upscaling of joining technologies that allow for structural integration of different materials in a cost and time efficient way, such as friction welding, self-piercing rivets, adhesives, or remote laser welding.

Enabling multifunctionality would require development of both the necessary materials, as well as the necessary process technologies, able to incorporate multiple micro-components into larger ones, where accuracy is key.

In both the above cases, it is important that such new components do not generate other issues beyond lightweighting. Multimaterial structures are by definition harder to disassemble and recycle, therefore it is important that the right measures are taken to make their EoL treatment easier. Such practices already exist or are under development, e.g. design-for-recyclability principles, reversible thermoplastic adhesives, or even common design interfaces that enable the transfer of a component to a new application, even after the former one has reached its EoL.

■ Develop resource efficient manufacturing technologies

These technologies aim to address both issues of cost, sustainability and resource usage. Such include higher automation – e.g. automated fibre placement in FRP – lower energy consumption – especially during the change of state of materials in aluminium and steel alloys – and improvement of near net-shape technologies in order to reduce scrap material. In order to achieve this, it is necessary to gain a better understanding of the physical and chemical processes taking place, making use of digital twins on one hand, and higher "resolution" and control of process parameters. Further resource efficiency can be achieved by the introduction of hybrid manufacturing processes utilizing the combination of new technologies like additive manufacturing combined with established production technologies.

IMPROVING TECHNICAL PERFORMANCE

■ Develop lightweight materials with improved performance and manufacturability

Work on materials could improve the crash and aging performance, as well as their manufacturability, which would in turn reduce cycle times and costs. Examples are 3rd generation Quenching and Partitioning steels (Q&P) by ThyssenKrupp with tensile strengths up to 1600 MPa and elongation A80 range of 9-45% which allow achieving lower thickness while maintaining structural properties; or pre-formed FRP parts which enable lower cycle times. In the aluminium space improved 6xxx and 7xxx series alloys with tensile strength up to 400 MPa allow for cold and hot forming, and more predictable forming behaviour. Other examples such as the Novelis fusion technology make use of the alloy surface as welding alloy, eliminating the need for filler material, and reducing manufacturing steps and therefore cycle times and cost .

IMPROVING MANUFACTURABILITY OF APPLICATIONS

■ Upscale recycling technologies and develop material with inherent sorting and recycling capabilities

Recycling of metals is already fairly advanced, partly due to the fact that metals have been around for longer, as well as because of the more straightforward process compared to e.g. FRP. Still, in the metals domain, there is work to be done to make separation of impurities and alloying elements – especially Si, Cu and Zn in aluminium – more efficient, while in FRP, work should focus on improving the separation of fibre and matrix and ensuring that both can be used in similar applications (instead of being downcycled in the form of powder or ash) with minimal degradation of fibre qualities. Examples are the solvolysis technology which is now at ~Technology Readiness Level (TRL) 6 , and the thermolysis technology, a variation of pyrolysis with lower temperatures, with reduces surface damage of the fibres from heat .

Recycling technologies could be coupled with materials with inherent properties, to increase recyclability rates, and quality of recycling output. An example is the "3R" thermoset resins developed by Cidetec, which allow for the matrix cross-links to be reversed after curing, for easy separation of matrix and fibres. Another example are thermoplastic adhesives, which reduce waste as they allow easy separation of polymer or even metal parts.

■ Develop tools and methodologies to accelerate the development and implementation of new technologies

The pace at which new technologies are being developed is increasing, with the threat that these are not optimally used. Support tools could help design and manufacturing engineers perform early assessments to choose the right material for the right application. Examples are Life Cycle Cost and Environmental Assessment (LCC, LCA) tools, the Target Weighting Approach that helps engineers prioritise application functions, or methodologies and AI supported design that helps design engineers adapt component designs to the properties of each material.

CONCLUSION

In conclusion, the future of lightweighting is moving from improving the performance of a single material, to gaining better understanding of how multiple materials can be combined in a single component. Combining functionalities is another strategy to reduce the number of components. This will require further development and combination of processing technologies which, besides enabling multimaterial and multifunctional structures, will also allow for reduction of costs and cycle times, and higher resource efficiency. To further improve resource efficiency and reduce impact on the environment, new materials with inherent sorting and recycling capabilities are under work. Finally, the necessary digital tools and methodologies are being developed, to ensure optimal use of materials.

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