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Rail lightweighting

A guide for OEMs

Trains set for a lighter future

- Rolling stock weight reduction is a key priority if the rail industry is to meet its capacity, efficiency, sustainability and operating cost reduction goals.
- In the quest for overall weight reductions of approximately 30 percent, rail OEMs are exploring the use of new vehicle architectures, materials and construction methods.
- Joining and bonding solutions using high performance adhesives and tapes are a significant enabler of lightweighting in the rail sector, providing safe, durable and cost-effective solutions to many challenging assembly applications.
- To achieve optimum performance, OEMs must adapt their component designs to suit the capabilities and properties of adhesive and tape systems. They must also ensure the bonding products they select are carefully matched to the loads, material characteristics and operating environment of their applications.

The rail sector faces considerable pressure to boost reliability and operating performance, reduce costs and increase energy efficiency. Vehicle weight reduction will be a significant part of its response to those challenges.

Energy, CO_2 and the need for change

Demand for rail travel has been rising steadily for more than three decades. Over the past 20 years the number of rail passenger journeys made each year in the UK has doubled, to more than 1.7 billion, with trains travelling more than half a trillion kilometres every year.[1–2]

Per passenger kilometre, trains produce less than a third of the CO_2 emissions of road transport, and an eighth of the emissions of air travel.[3] The rail sector's current good performance does not, however, exempt it from the pressure to achieve further efficiency improvements. As part of global efforts to combat climate change, the UK has signed up to aggressive CO_2 reduction targets. The Fifth Carbon Budget, signed into law in 2016, creates a legally binding obligation for the country to reduce its overall carbon emissions by 57 percent by 2030, using 1,990 emissions as the baseline.[4] Meeting these targets will require action across all industries and a significant reduction of energy. The long operating life of railway assets means that the trains being designed and built today will still be in operation long after the 2030 emissions deadline has passed.

Moreover, rail operators have significant economic reasons to reduce their energy consumption. Energy currently accounts for around 10 percent of overall operating costs for train operating companies (TOCs).[5] For trains using diesel traction, energy efficiency improvements provide direct fuel cost reductions for operators, as well as reduced exposure to volatile oil price changes. On electrified parts of the network, the shift from modelled estimates of power consumption to directly-metered billing provides greater incentive for operators to reduce energy use.[6]

The significance of weight for train efficiency

The weight of rail vehicles is closely linked to their overall energy consumption. As a proportion of this, vehicle mass has the largest impact on energy use for urban and commuter trains - where accelerations between frequent stops can account for 70 to 80 percent of the overall energy requirements.[7] The proportional impact of weight is lower for high speed inter-city services since these trains make fewer stops and have improved aerodynamic characteristics. Overall, however, the high speeds and greater distances covered by these trains require more energy, so lifetime absolute cost savings provided by weight reduction are higher.[8]

Research by industry body the Rail Safety and Standards Board (RSSB) indicates that reducing the weight of new trains is the single most cost-effective intervention the rail industry can make as it seeks to reduce its CO_2 emissions.[9] Its calculations, which were based on a 20 percent reduction in overall vehicle mass, suggest that lighter trains actually save their operators more than £300 for every tonne of carbon emissions they prevent. The additional capital costs associated with lighter-weight vehicles pay back more than twice over the operating life of the assets.

Weight reduction provides other benefits beyond efficiency improvements. Notably, the weight of a train has a significant effect on the damage it causes to the track, and hence to maintenance and renewal costs. Modelling by the RSSB suggests that the savings in track costs delivered by train weight reduction are equal to the energy cost savings on suburban routes, and more than three times greater on inter-city routes.[10]

Combining the energy consumption and track cost benefits over the 30 year life of a train, the RSSB estimates that each tonne of weight reduction delivers a benefit of between £8,400 and £11,900 for metro services and between £28,700 and £40,400 for inter-city trains.[11] These figures are conservative, since they assume no increase in energy or maintenance costs over the operating life of a train. Using them as a basis suggests that reducing the 590 tonne weight[12] of an inter-city train by 10 percent could deliver lifetime savings of almost £2.4 million.[13]

Weight reduction opportunities

The equipment used to propel a train, including powered bogies, motors, drives and associated propulsion equipment, accounts for around a third of a trains weight. Trailer bogies make up a further 15 percent. The remaining weight, just over half the total mass of the vehicle, is found in the train's car bodies, interiors and ancillary equipment.[14]

Opportunities to reduce weight exist in all these areas. Reducing the mass of the bogies is particularly significant in terms of impact on rail infrastructure, since unsprung weight has a disproportionate impact on track damage. Rail OEMs are using a variety of strategies to reduce the overall weight of these systems. For example, through the use of articulated designs that allow two carriages to share a single bogie set.

For many operators, weight reduction achieved through changes to car bodies and interior systems is of particular interest. These components tend to be purchased and upgraded more frequently than propulsion components, so providing a potentially faster route to overall fleet weight reduction.

Changes in safety regulations, along with evolving passenger expectations, have led to significant increases in passenger car weight. Some UK carriage designs from the turn of the Millennium, for example, were 40 percent heavier than their counterparts from the 1970s.[15] Now rail sector OEMs and their suppliers are working hard to reverse this trend, adopting new materials, new construction techniques and new design approaches to achieve significant weight savings.

To make trains lighter without compromising safety, reliability or durability, the industry is increasingly turning to technologies first developed in other sectors, like aerospace, that have already faced similar challenges. This is leading to the adoption of advanced composite materials, including carbon fibre reinforced plastics and laminates using honeycomb materials or foams. These materials are not only lighter than conventional alternatives, they can also be engineered to perform multiple roles, allowing trains to use fewer components and making them faster to build.

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The role of adhesives and tapes

Advanced materials create new manufacturing challenges. They include the need to create durable connections between dissimilar materials. Thus avoiding stress peaks around fasteners and preventing water, ingress and corrosion getting into and between, components. OEMs also need construction technologies that work reliably and consistently in the production environment.

Advanced adhesive bonding technologies such as 3M™ VHB™ Tapes and the Scotch-Weld™ Structural Adhesives allow manufacturers to achieve those aims. Adhesive bonding allows structural connections to be made between many different materials. This is a significant advantage in designs that include both metal and composite or polymer components. Where dissimilar metals are joined, such as aluminium body panels to a steel frame, an adhesive or taped joint provides electrical insulation, reducing the incidence of galvanic corrosion. With the correct joint design, adhesive bonding ensures loads are carried by the entire joint, allowing the use of thinner, lighter-weight materials. Bonded joints can secure and seal a structure in a single operation and they can also be designed to reduce the transmission of sound and vibration.

For carriage interior components, bonding using 3M™ Scotch-Weld™ Structural Adhesives and 3M™ VHB™ Tapes gives designers the opportunity to save weight while also creating systems that are robust and easy to look after. Advances in the chemistry of adhesives mean that lightweight, low surface energy polymers such as polypropylene (PP) and thermoplastic polyolefin (TPO) can now be bonded reliably, without the need for costly and time-consuming surface treatments. Reclosable tapes, such as 3M's Dual Lock™ range, allow the installation of removable panels or upholstery elements with a clean aesthetic finish.

Performance and durability

Adhesive bonding of structural components has been around for over 60 years. Over that time, bonded joints have demonstrated their reliability and durability in applications with extended operating lives and in demanding environments.

The Fokker F27 Friendship passenger aircraft, for example, incorporates a bonded aluminium structure using 3M™ Scotch-Weld™ Epoxy Adhesive 2216. The design went into production in the late 1950s and many early examples are still in use today.

In the oil and gas sector, 3M™ Scotch-Weld™ Epoxy Adhesive DP490 is used to bond carbon fibre and stainless steel components in lightweight shale shaker equipment. In this application, the bonded joints vibrate several hundred times a minute and experience accelerations of up 70ms^{-2}. They must also resist exposure to a 100°C mixture of oil, mud and fragments of rock.

These applications have been very successful, with durable bonded constructions and parts providing not only performance benefits but also good long-term durability. Adhesively bonded joints can resist high loads - including fatigue, different environments and degrading agents such as fuel and solvent based cleaners.

Design considerations

To capture the full performance and weight reduction benefits available from the use of adhesive bonding, it is important that the joint design and choice of adhesive are appropriate for the applied loads, operation conditions and the characteristics of the materials involved. The strength of a joint depends on both the quality of adhesion achieved, the cohesive strength of the cured adhesive and a selection of an adhesive with an appropriate stiffness (modulus of elasticity). The joint design must also consider the most appropriate mode of failure for the joint.

In safety-critical applications such as rail passenger car interiors, materials must comply with stringent fire, smoke and toxicity (FST) regulations. While these requirements were once seen as a barrier to the adoption of certain materials, manufacturers have made significant progress in the development of a wide range of resins, fibres and coatings, adhesives and tapes all with excellent FST performance.

When adhesives are used to join thin materials – a common requirement in lightweight rail interior applications - it is important to select an adhesive/ material combination and bonding process that avoids “read-through”. This is the tendency for distortion during or after assembly to allow the bond line to become visible on the outside of the material.

Environmental, economic and operational factors are increasing the demand for significant rail vehicle weight reduction. Bonded construction methods, using high performance adhesives and tapes, have a significant role to play in the industry’s lightweighting strategies.

Bonding can contribute to direct weight savings by replacing mechanical fasteners, or allowing the elimination of additional sealing insulation or soundproofing components. It can allow the use of lighter-gauge materials by eliminating stress concentrations and allowing optimal load distribution across component interfaces.

It is a key enabler in the adoption of new materials and design approaches, such as the use of lightweight composite parts.

So what can 3M do for your business?

Ask a 3M Expert

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