GRANTA TEACHING RESOURCES

Engineering Level 3

Case Study: RAILWAY

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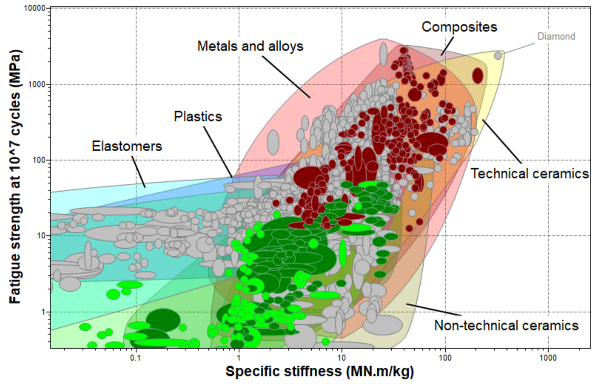
1. Challenges in Transportation

Railways provide an essential transport system in modern society and were one of the key components of the industrial revolution. The history of guided paths goes back to the ancient Greeks, well before the current era (BCE), however, the first steam-based locomotive reminiscent of today's trains was introduced at the beginning of the 1800's. It was soon used both for heavy goods and for passenger transport. The materials and components currently used in trains have evolved over time, resulting in an established, regulated and standardized technology.

The increasing concern for the environment and climate change, as well as the arrival of high-speed trains, have focused attention to lightweighting. Reducing the mass of trains would both reduce energy need and track damage, as well as facilitating acceleration and braking. Weight reductions have already been extensively adopted by the aerospace and automotive industry and have been identified as strategic by the European and UK rail sectors to deliver improved capacity and performance.

2. How to tackle the Problem

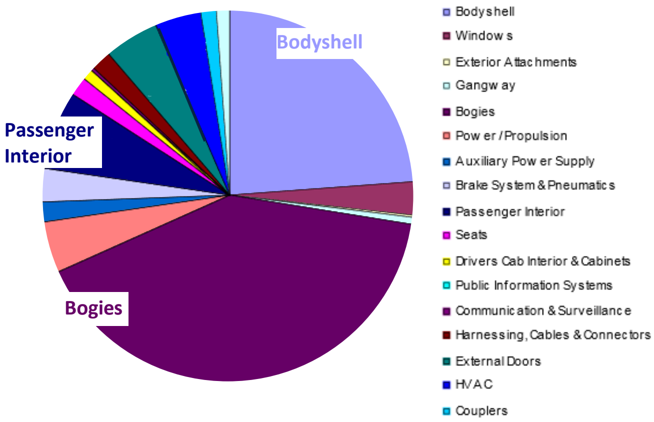
In EduPack, the function of a component and the expected load situation need to be specified so that a systematic selection via screening and ranking can be applied to find the best material candidates. The design limiting property also needs to be fixed, in our case this would be stiffness or strength. Of course, strength is always important and for trains many loads can be considered cyclic, meaning that the fatigue strength is relevant. However, the property to optimize might also be related to stiffness, or specific stiffness (modulus divided by density), since we are interested in component lightweighting. Strength is then considered as a constraint with a minimum value to ensure safety.



An overview of these two relevant properties show that the most resilient materials are composites (dark red) and metals (greyed out here). They would probably be the best engineering material options for many load-bearing components in a train when looking to reduce weight. The nature of the load, of course, will depend on the part.

*Bettendorf truck © **Sean Lamb (CC BY-SA 2.0)** at Wikimedia*

Bogies (or trucks) dominate the weight but have also evolved significantly over many years of experience to comply with safety standards and regulations. Whereas materials are difficult to improve, the axles are numerous and mechanically interesting to lighten by shape. They typically constitute around ⅓ of each wheel set mass.

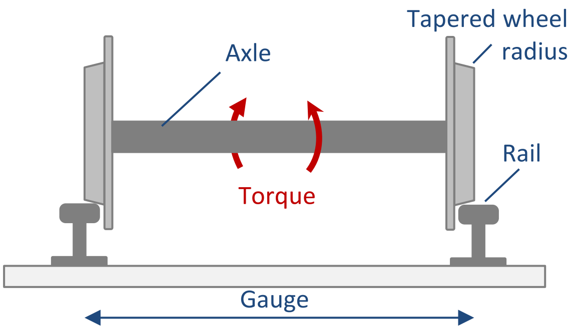


Some standard parts, such as car body panels, interior details of passenger trains and decking on freight cars may be more suitable to improve by material selection and can be significant when considered in large numbers.

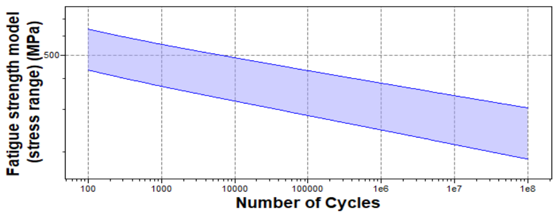
3. What can EduPack do?

We will discuss three types of lightweighting that can be assisted by EduPack. (i) Exploring hollow wheelset axel materials, (ii) replacing steel and aluminum parts of a train body with magnesium and (iii) replacing decking, chassis or door panels by sandwich panels (structural hybrids).

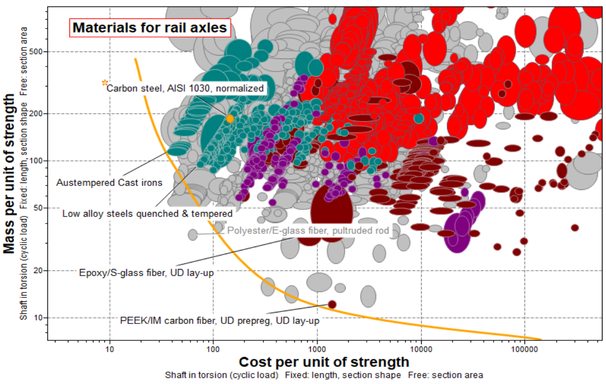
Since the wheels are fixed to the axle you would expect torque arising from different distances travelled in curved rail tracks. Most of this, however, is avoided by a clever tapered design of the wheels. Some torsional load will prevail, though, coming from centrifugal forces or slopes interfering with this mechanism, and uneven braking etc. For safety reasons, the axle is limited by fatigue strength.



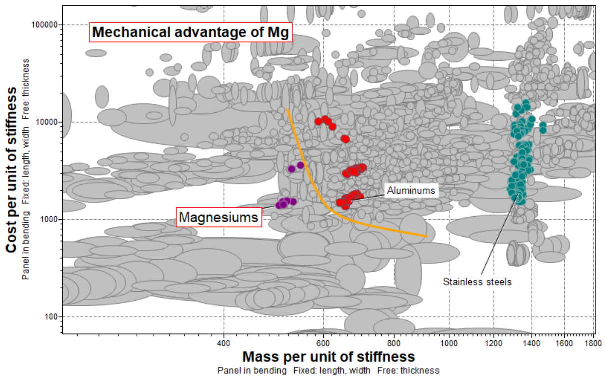
European axles are typically manufactured by open die forging or a rolling process from vacuum-degassed EA1N grade railway steel. This will be approximated by AISI 1030 normalised carbon steel, which contain fatigue data.



This reference material can be added to *Favourites* and highlighted by right-clicking to change bubble color to orange. The *Performance Index Finder* for mass and cost in strength-limited design for hollow shafts in cyclic torque was used, limited to metals and composites. A tree stage filtered for water durability and hollow shape. This excludes many high performing composites, but indicates that *austempered cast irons* and heat treated *low alloy steels* could be considered as improvements to EA1N.

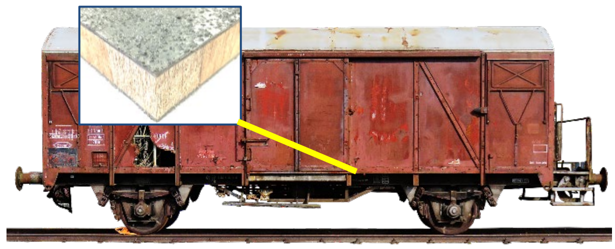


The second example illustrates lightweighting by material substitution. Most train bodies are currently constructed by extruded Al alloys or Stainless steels. The mass and cost performance for panels in bending and a stiffness-limited design is shown for Mg, that has been suggested.

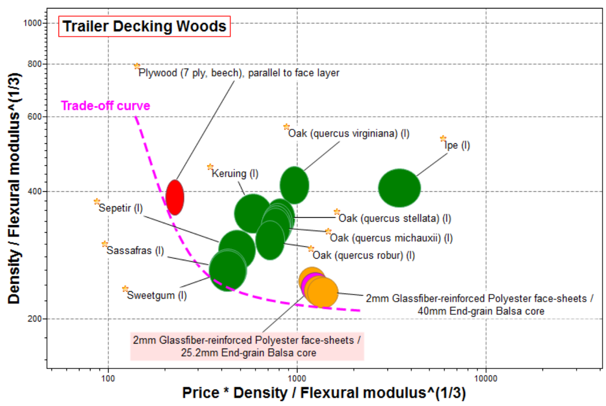


The plot shows that indeed, Mg alloys (purple) perform better than Al grades (red) or Stainless Steels (teal).

The third example of lightweighting considers the introduction of a sandwich panel as a structural hybrid to replace decking or floor panels by plywood or oak, for example. This is similar to what is used for light bridges.



The results below shows the trade-offs, enabled by data on a large number of woods, plywood (considered a natural material structural hybrid) and the abiliity to estimate properties for a sandwich panel of end-grain balsa with glass fiber reinforced polyester (GFRP) faces.



4. Reality check and conclusions

In this industrial case study, we have explored the possibility to select, compare and assess materials for railway lightweighting using EduPack. Hollow axles, Mg car bodies and sandwich panels have all been considered in national strategies and international research projects, such as MODURBAN, to improve transport performance.