Lightweight Design of Interior Components for Energy Efficient Metro Vehicles

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NewRail

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Lightweight materials

- If there are cost and energy benefits associated with lightweighting, why isn’t there a greater use of lightweight materials, such as composites, in rail vehicles?
- Clearly, there are some technical issues relating to composites to be resolved (design complexity, cost, recycling, fire performance, volume manufacturing, etc).
- But are there some more general rail industry barriers to be overcome?
- The MODURBAN European project recently examined this issue from the perspective of rail vehicles.

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MODURBAN: “Removing Constraints on the Use of Lightweight Materials”

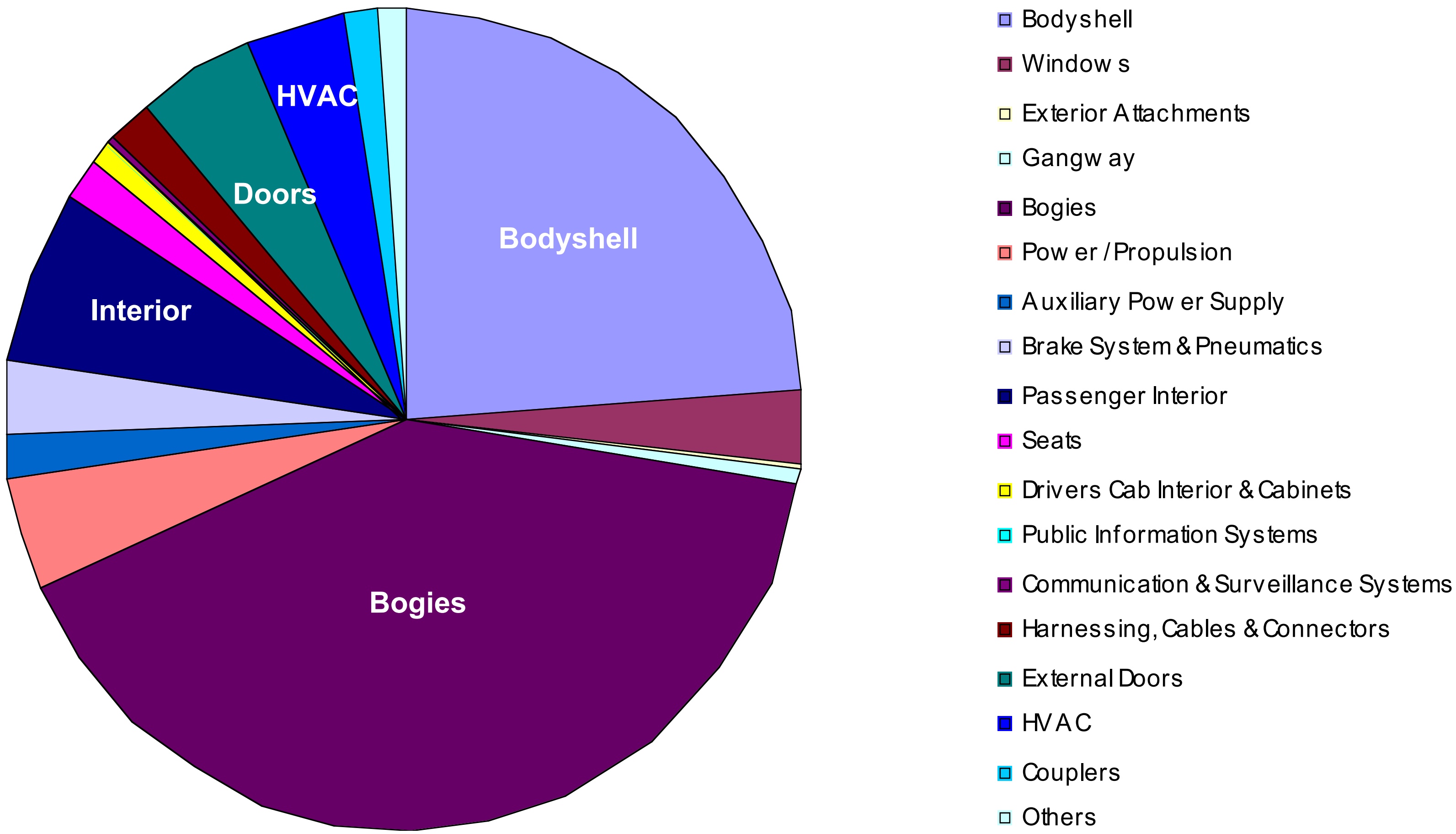
“ … to provide engineers in urban vehicle production with lightweight materials, concepts and designs in order to provide affordable vehicles with reduced weight” (and reduced energy consumption)

newrail ALSTOM ANSALDOBREDA

atac SPA BOMBARDIER [redacted]

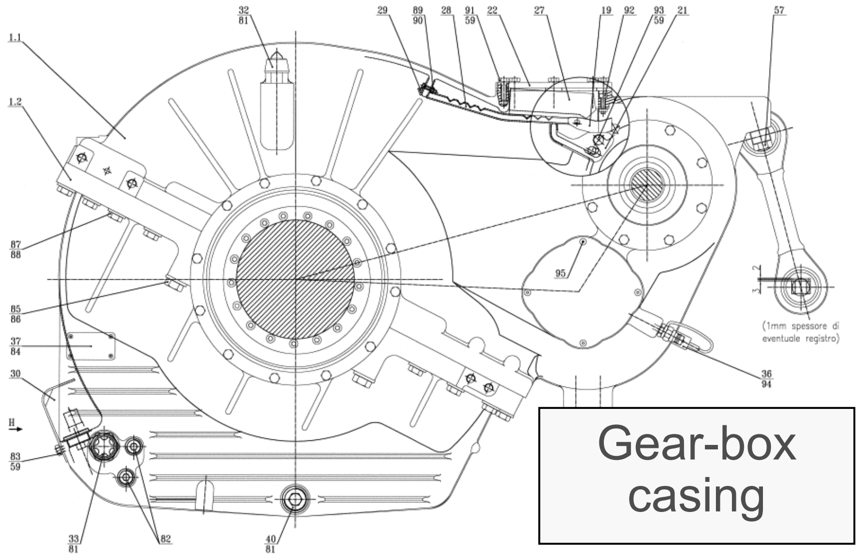
MODUrban

Typical state of the art metro vehicle: mass breakdown



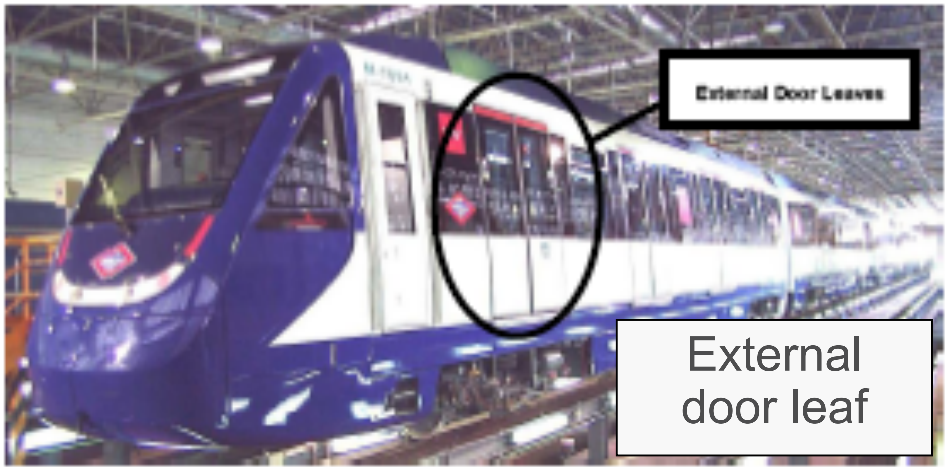
Four case studies

Grab rail



Gear-box casing

Floor panel



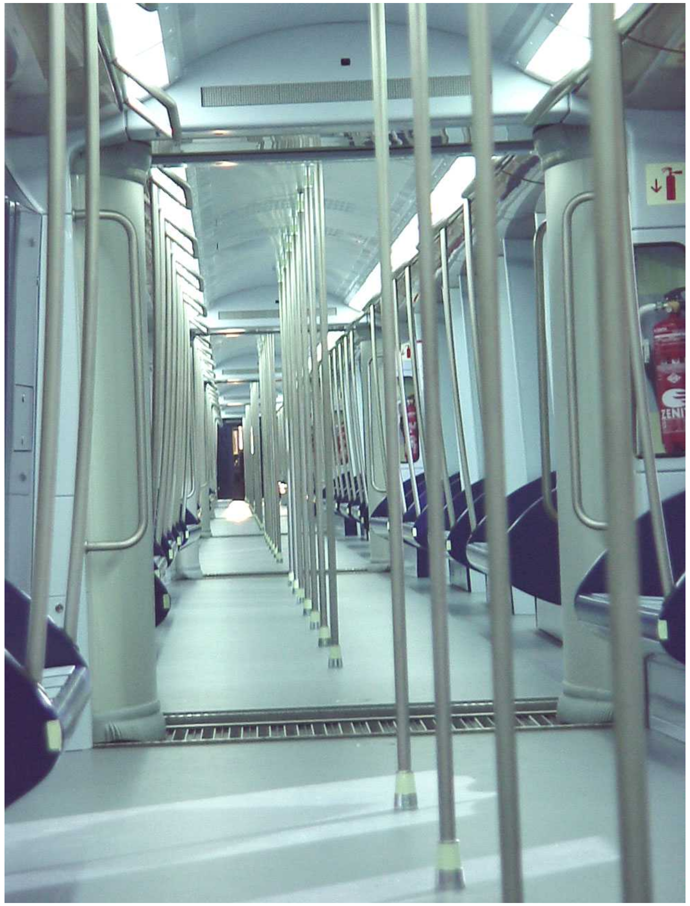
External door leaf

Case studies

Component	Individual Mass	Number per Six Car Metro Set	Overall Mass per Six Car Metro Set
Grab Rail	3.9 kg	180	0.7 tonnes
Gear-Box Casing	345 kg	16	5.5 tonnes
External Door Leaf	36.2 kg	96	3.5 tonnes
Floor Panel	10 kg/m^2	250 m^2	2.5 tonnes
		Total:	**12.2 tonnes**

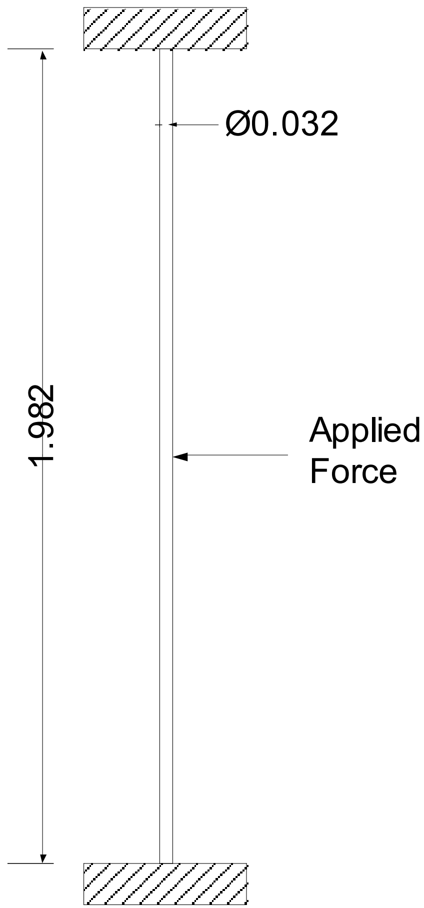
Example – grab rails

- Consider metro vehicle interior grab rails.
- Currently, these are typically made from stainless steel, steel or aluminium.
- Grab rails typically add more than half a tonne to the mass of a metro vehicle.
- ***Is there a material that could provide a lighter solution at similar cost and performance levels?***



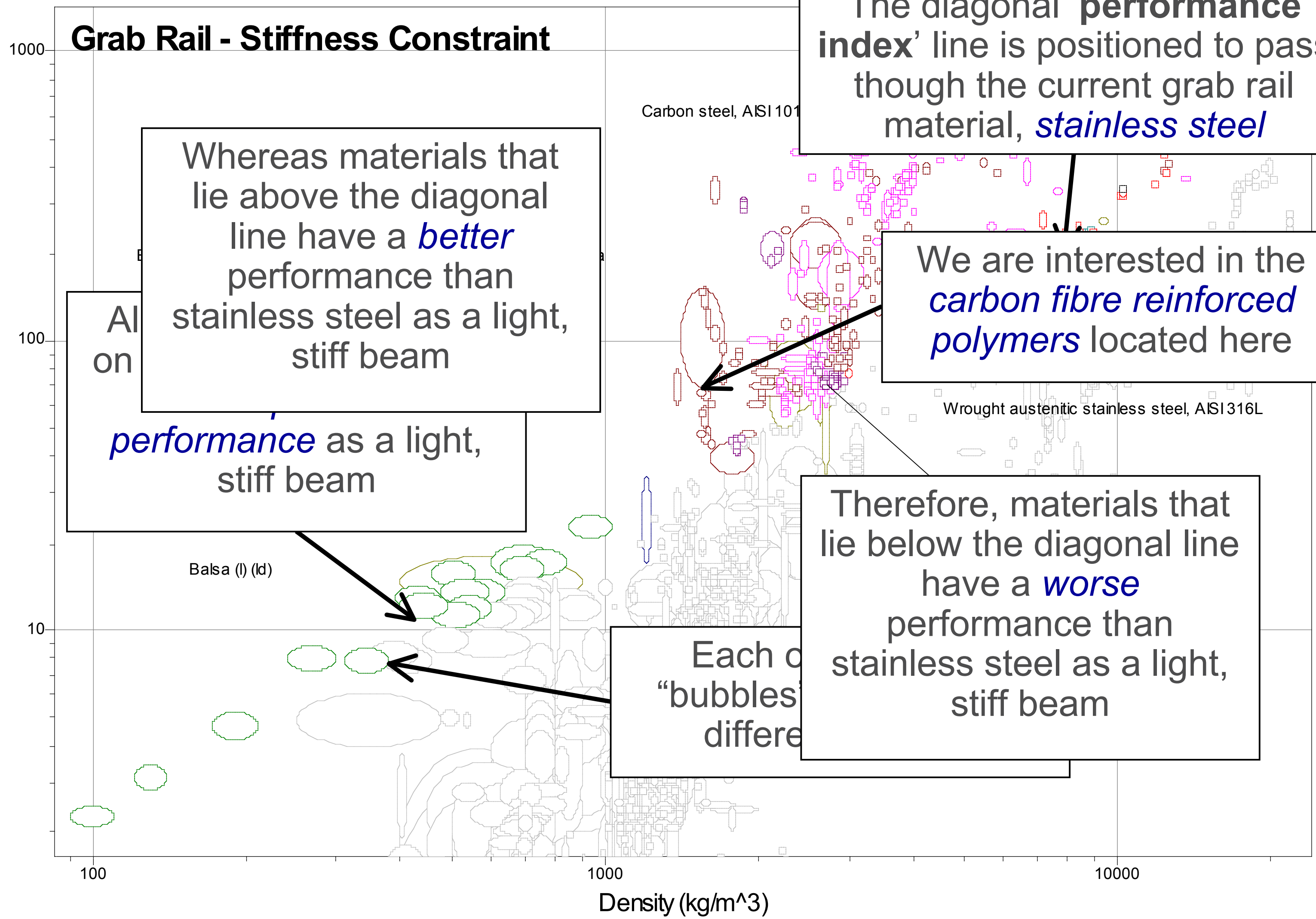
Problem definition

- Function:
  - Stiff beam to add the stability of standing passengers.
- Objective:
  - Minimise mass.



Problem definition (continued)

- Constraints:
  - Length and radius fixed.
  - Must be sufficiently stiff to support passengers.
  - Must not fail by fatigue in bending.
  - Must have a natural frequency above 30 Hz to avoid vibration issues.
  - Must have adequate fire performance.
  - Must be cost comparable to existing solutions.



The diagonal '**performance index**' line is positioned to pass though the current grab rail material, *stainless steel*

Whereas materials that lie above the diagonal line have a *better* performance than stainless steel as a light, stiff beam

Al
on
performance as a light, stiff beam

We are interested in the *carbon fibre reinforced polymers* located here

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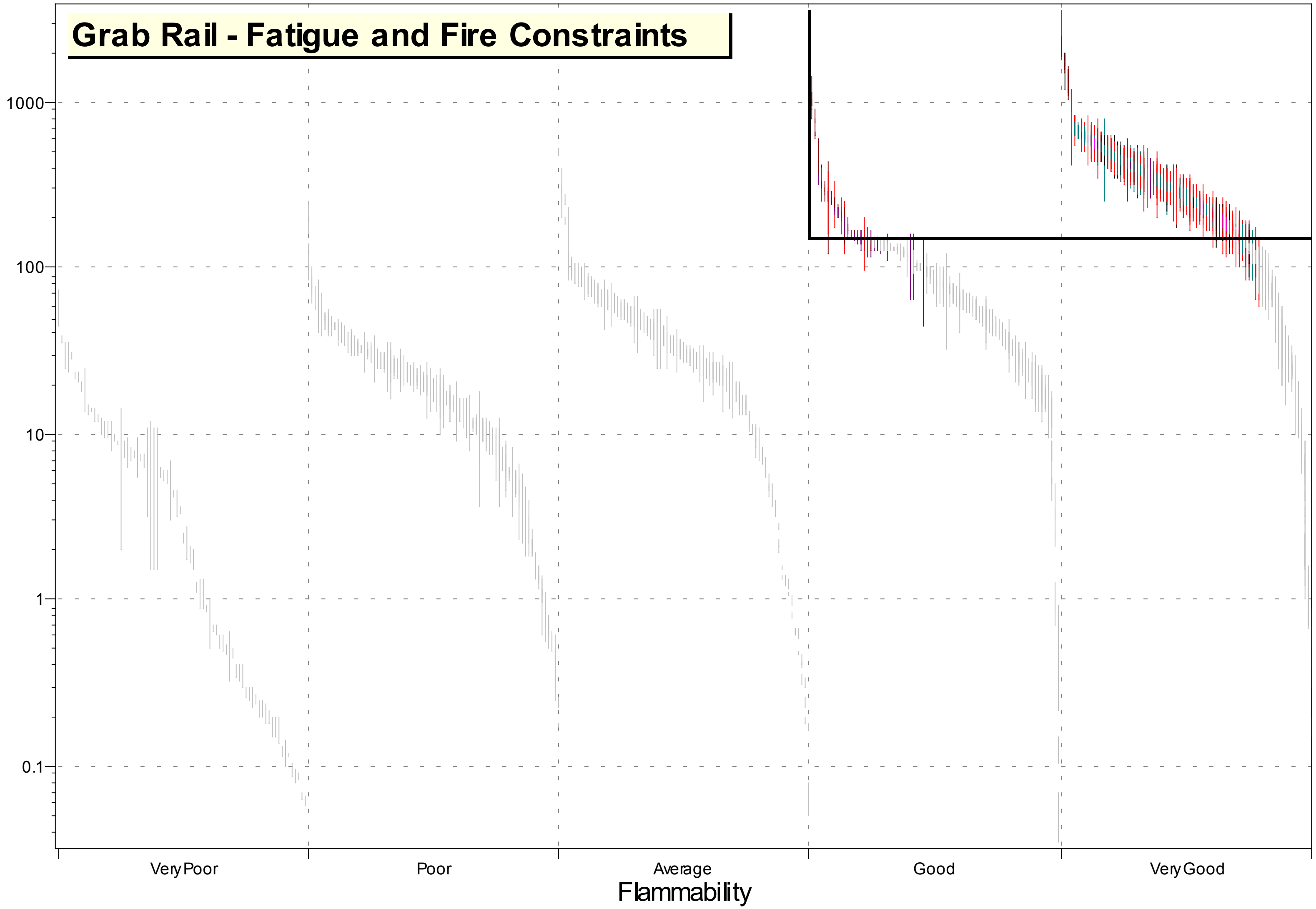
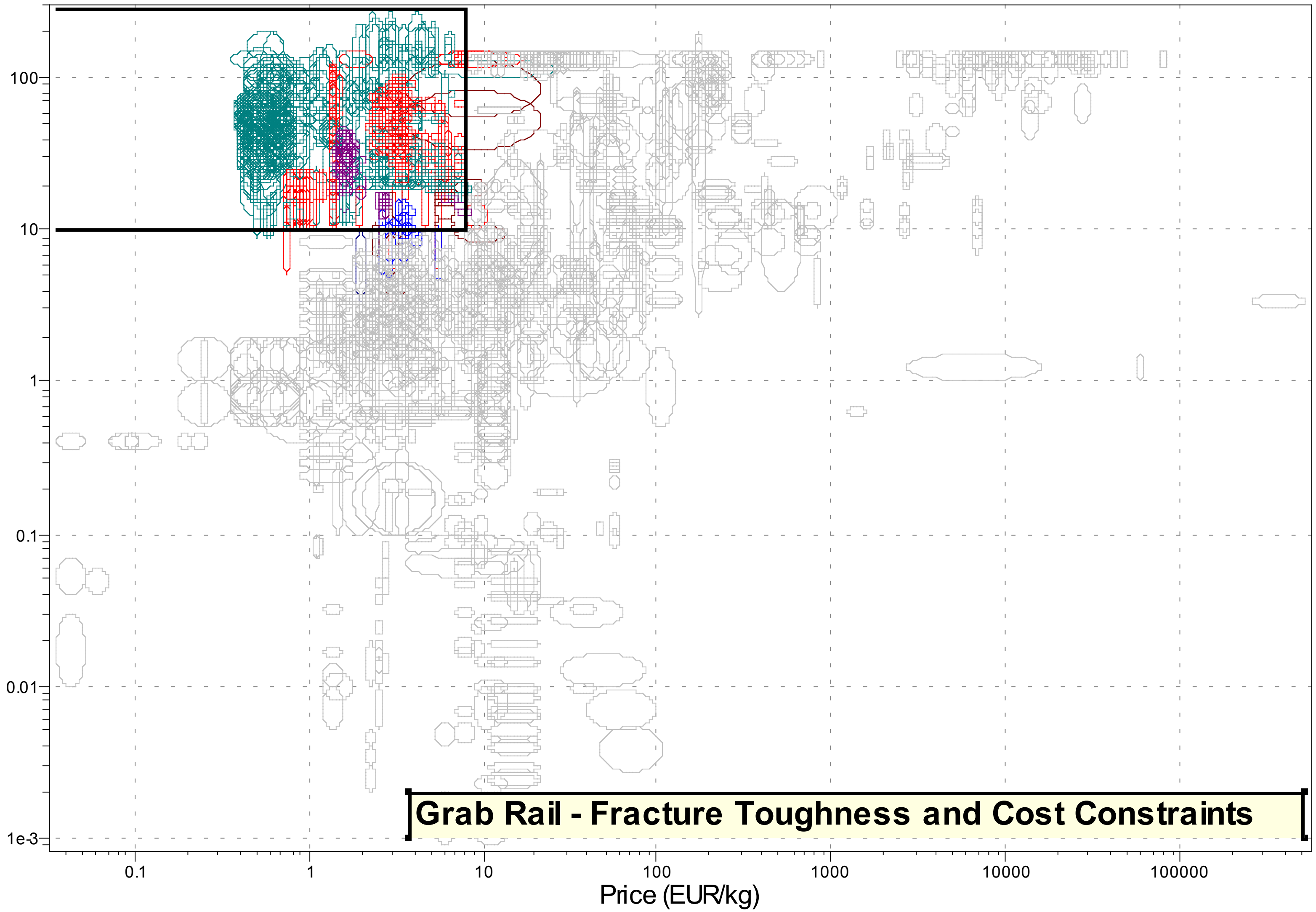
differe

Therefore, materials that lie below the diagonal line have a *worse* performance than stainless steel as a light, stiff beam



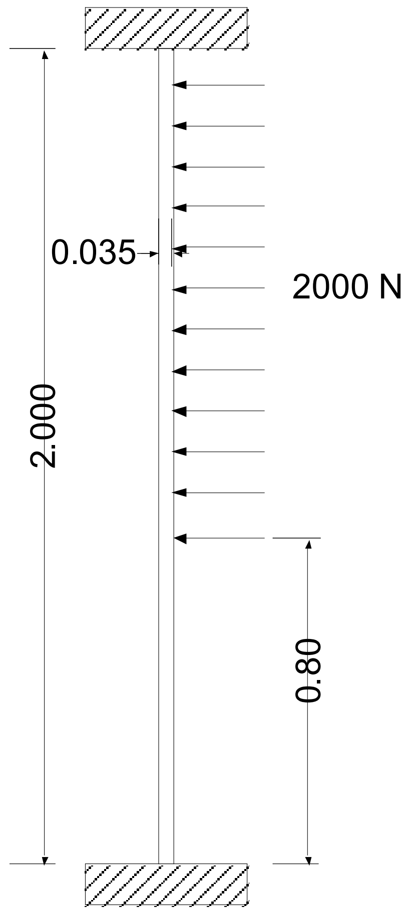
Grab Rail - Fatigue and Fire Constraints
1000
100
10
1
0.1
Very Poor
Poor
Average
Good
Very Good
Flammability



100
10
1
0.1
0.01
1e-3
0.1
1
10
100
1000
10000
100000
Price (EUR/kg)
Grab Rail - Fracture Toughness and Cost Constraints

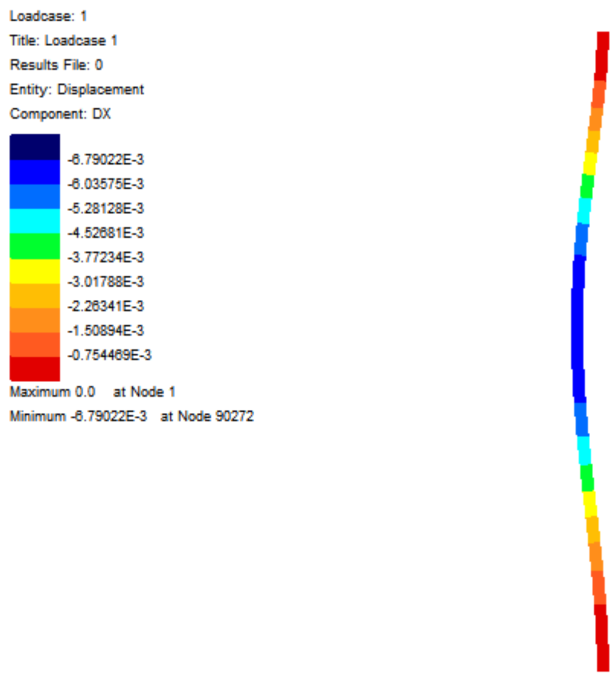
Lightweight grab rail: detailed design

- The CES material selection software suggested that a grab rail manufactured from a ***carbon fibre reinforced polymer*** would provide a significant weight saving.
- For the load case shown, a typical stainless steel grab rail would have a predicted maximum deflection of 6.3 mm.
- Can a **carbon fibre reinforced polymer** grab rail really provide similar performance with reduced mass?



Lightweight grab rail: predicted weight saving

- Material = carbon fibre reinforced modified acrylic.
- Outside diameter = 38.1mm.
- Wall thickness = 6.35mm.
- Maximum deflection for previous load case = 6.8 mm (i.e. similar to stainless steel).
- Weight saving compared to stainless steel = 57%.



Lightweight grab rail: wider design aspects

- The modified acrylic matrix resin and paint system employed have been specified to provide the required levels of ***fire performance***.
- The paint system has also been specified to provide the required resistance to ***scratching***, ***impact***, ***chipping***, ***abrasion*** and ***graffiti***.

Lightweight grab rail: prototyping

- The lightweight carbon fibre reinforced polymer grab rail has been prototyped by ***Exel Composites UK***.
- ***Real (measured) mass saving = 57%***.
- The prototypes were produced using a continuous manufacturing process known as ***pullwinding***.
- In sufficient volumes, the resulting tubes are ***less costly*** than the equivalent stainless steel.

Lightweight grab rail: demonstration

Summary of mass saving benefits

- Using the MODURBAN energy model it has been estimated that a 10% saving in metro vehicle mass would provide:
  - A 7% saving in energy consumption.
  - A 100,000€ annual cost saving per vehicle due to reduced energy consumption.

Wider issues associated with the introduction of new materials

- It would be beneficial (from a lightweight design perspective) if customers were to replace prescriptive material specifications (e.g. "*the grab rail shall be made from satin-polished stainless steel or aluminium*") with functionally-based component requirements (e.g. "*the grab rail should deflect no more than 5 mm under a central point load of 1000 N*").
- The commercial risk and supplier / customer engagement associated with the introduction of new material technologies needs to be carefully managed, perhaps through limited pilot programmes.
- Life cycle assessments may support the case for new materials.

With thanks to the European Commission ...

- ... for supporting MODURBAN under contract number TIP4-CT-2005-516380 ...

And Exel Composites UK ...

- ... who kindly prototyped the lightweight grab rails.

For more information ...

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  - www.newrail.org
- ... and see:
  - Carruthers, J.J., Calomfirescu, M., Ghys, P, Prockat, J., “The application of a systematic approach to material selection for the lightweighting of metro vehicles”, *Proceedings of the Institution of Mechanical Engineers Part F: Journal of Rail and Rapid Transit,* 223(5), 427-437, (2009).