



Level 3 Industrial Case Study

Automotive Door Panels



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Summary

Granta EduPack is widely used to teach engineering and design in higher education. It explicitly supports informed materials decisions, which is very useful for both teaching and training. One way to engage the students is by case studies. The more realistic the case study, the better it is. Here we focus on a selection and benchmarking example for polymer door panels in modern cars.

The current focus on reducing environmental impact and lightweighting is forcing many companies to consider new materials. Identifying cost-effective alternatives with sufficient mechanical performance can be difficult, as most cost models require detailed information about the component, which isn't available in the early stages of design.

In this case study, we have investigated the lightweighting of an automotive exterior door panel. Inspired by the plastic panels of the **Smart ForTwo** car, we studied the suitability of this class of material as a replacement for steel. The selection procedure is described in detail and the result is then compared with the actual material used in the car. Furthermore, we use the Synthesizer tool to create a natural fiber composite for high performance and compare this in the part cost estimator with steel, aluminum and polymer options.

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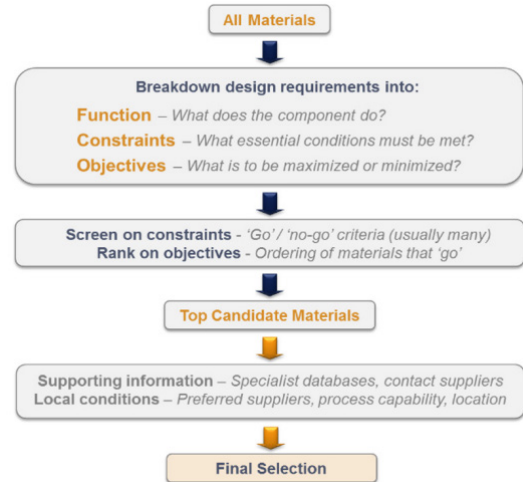
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1. What is the scope?

The use of Thermoplastic Olefins (TPOs), such as polypropylene, in the automotive industry has increased significantly over the past 10 years. Because of their attractive properties, these are increasingly substituting other plastics. In 1995, for example, only 9% of bumpers were made of TPOs, but by 2005 the figure had risen to 67%. Over the same period, consumption of Polycarbonates and Polybutylene Terephthalates for this application dropped from 18% to 4%. Are these materials suitable for automotive door panels? If not, which ones are? And how are they performing against other alternatives? These questions are investigated in this advanced industrial case study for Granta EduPack. We will use the polymer database throughout.

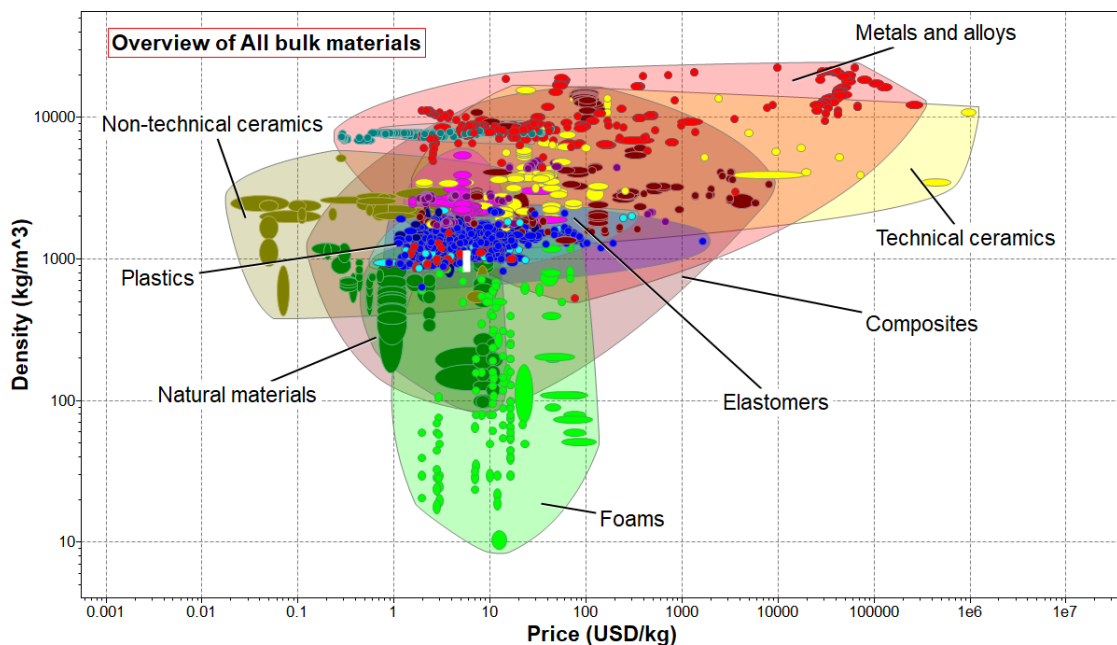
2. How to tackle the problem

Granta EduPack provides a systematic approach based on the work of Professor Mike Ashby [1]. You can identify materials that meet your requirements and study the trade-off between different objectives. This enables an informed material choice based on the widest range of available information, while maintaining traceability to facilitate critical discussions about decisions. This is particularly important for higher education. A schematic description of a typical design process is shown to the right, from the Design Requirements to the Final Selection.



3. How to use Granta EduPack to perform materials selection

The basis of the selection is the data records for nearly 4000 engineering materials available in Level 3 of Granta EduPack. An overview of the subset **All bulk materials** at Level 3 is shown in the *density vs price* chart below. These are not all candidates for the door panel. For example, ceramic materials are too brittle while foams, fibers and particulates are structurally unsuitable. A better starting point for the selection if we want to consider a realistic and open-ended investigation, would be all metal alloys in the ferrous (steels) and Al alloys (light metals) in the non-ferrous data folders, as well as plastics and polymer composites. These can be included in a custom (define your own) subset, as shown below. This removes the unsuitable materials mentioned above.



Function:

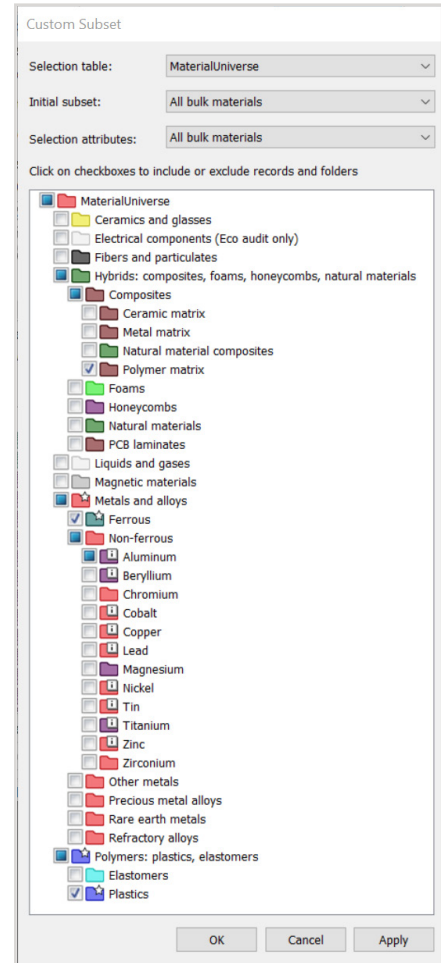
Expressed simply, the engineering application here is a **panel in bending** limited by **stiffness** (we do not want the panel to deflect too far). Within the graphical user interface, we can relatively quickly generate a graph which shows the trade-off between mass and cost in this context. The chart is created with a **Custom** subset of the MaterialUniverse data set, using “Create your own subset...”, as discussed above. The resulting chart is seen on the next page.

Constraints:

In the Granta EduPack software, we begin selection by screening the chosen composites, metals and plastics against some of the key requirements for the panel (e.g., strength, min and max service temperatures, resistance to water etc). The materials that pass these constraints, summarized below, appear interactively on the materials property chart making the final choice less exhausting. The requirements considered for the automotive door panel are:

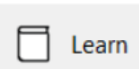
List of constraints:

- Maximum Service Temperature (+90°C or more)
- Minimum Service Temperature (-20°C or less)
- Adequate Yield strength > 22.4MPa
- Fracture toughness > 1.17MPam^{0.5}
- Resistant to (acceptable/excellent): rain (water), petrol (organic solvents)
- Manufactured by composite forming, sheet deformation or molding processes

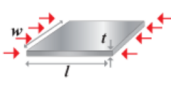


Objectives:

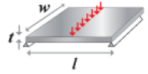
A Table of common performance indices can be found under Material Selection by clicking on the Granta **Learn** button embedded in the main toolbar of the software. In order to search for optimum values, it is convenient to look at materials towards the origin of the property chart, therefore we chose to **Minimize** the performance indices (see Tables below). For **low weight** and **low cost** in a stiffness-limited design, we need to minimize: $M_1 = \rho/E^{1/3}$ (mass) and: $M_2 = C_m * \rho / E^{1/3}$ (cost). These can be plotted on the Y-Axis and X-Axis, respectively, as described on the next page.



Stiffness-limited design at minimum cost

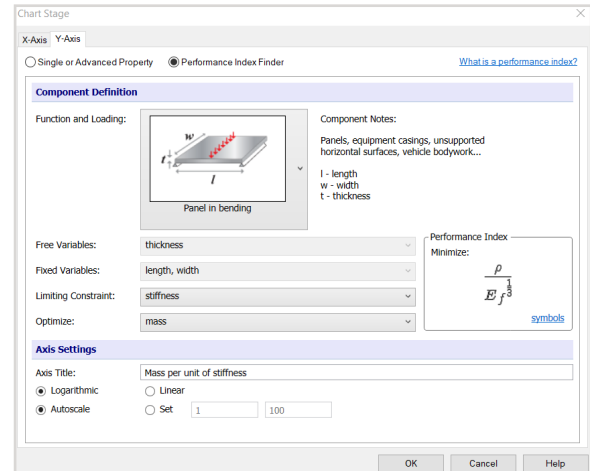
FUNCTION AND CONSTRAINTS		MAXIMIZE ¹	MINIMIZE ¹	
Panel in compression		collapse load, length and width fixed; thickness free	$E_f / C_m \rho$	$C_m \rho / E_f$

Stiffness-limited design at minimum mass

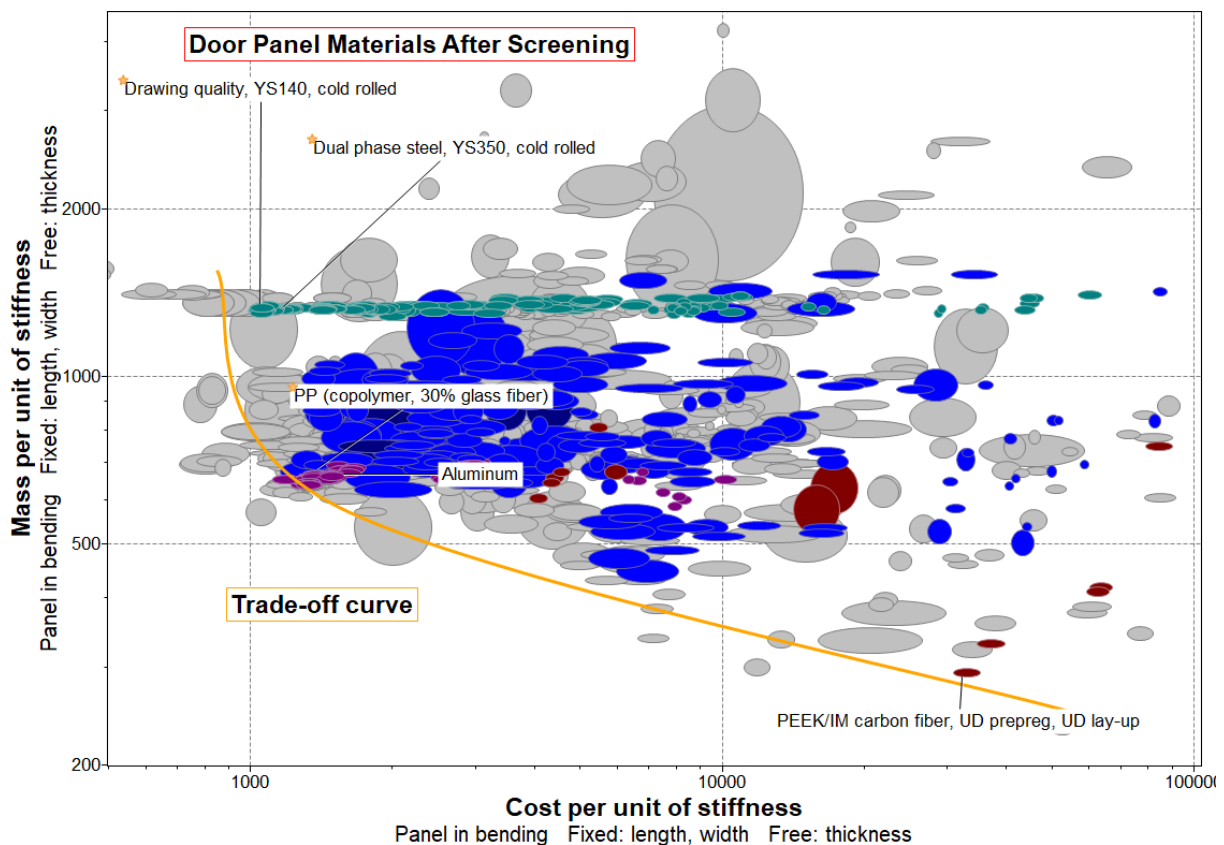
FUNCTION AND CONSTRAINTS ¹		MAXIMIZE ²	MINIMIZE ²	
Panel in bending		length, width fixed; thickness free	$E_f^{1/3} / \rho$	$\rho / E_f^{1/3}$

4. Trade-off and benchmarking

In Granta EduPack, there are two ways of entering the above-mentioned objectives into a chart. First, the advanced button in the Chart stage, giving access to the editor for properties and operators to create performance indices for each axis. Second, the new Performance index finder, where you enter the function loading conditions and choose constraints and objectives from drop down menus. The axis titles become slightly different, but the property charts are the same. The resulting chart after materials are screened (grayed out) is shown below. Among the remaining materials in the property chart, the 'best' ones are those along the trade-off curve, which is a boundary line that can be sketched at the lower left edge of the bubbles (orange line).

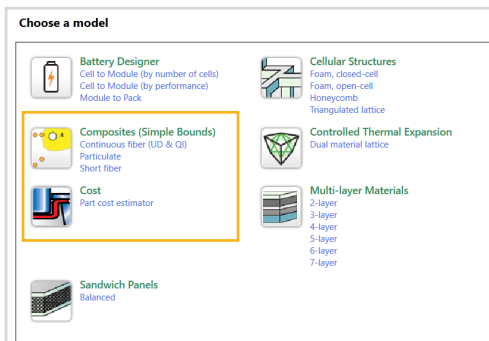


We can see by the color coding that there are all types of materials, thermoplastics, composites, ferrous and non-ferrous metal alloys near this trade-off curve (Pareto front). Lightweight metal alloys, i.e., aluminum alloys (Aluminum, 6022, T62), are indicated in the chart below for comparison (in purple). Polymers (in blue) are attractive materials comparable in performance to aluminum if lightweighting is important. Composite materials (in red) are favorable if lightweight is very important and cost is not so much of an issue. Polypropylene with 30% glass fiber reinforcement appears the best Polymer option but a lot of other Polymers come close. We can also think of new composite materials, for example a polymer matrix reinforced with natural fibers. Such materials would be interesting from an environmental perspective and might be plausible for a concept car. We will explore this option with the help of the Synthesizer tool in the next section.



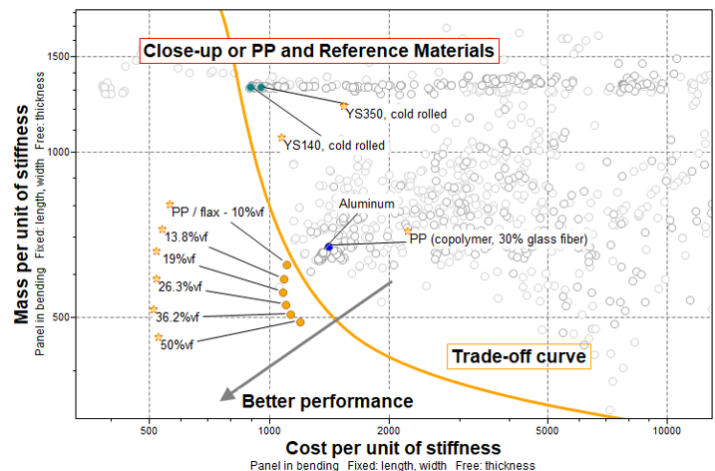
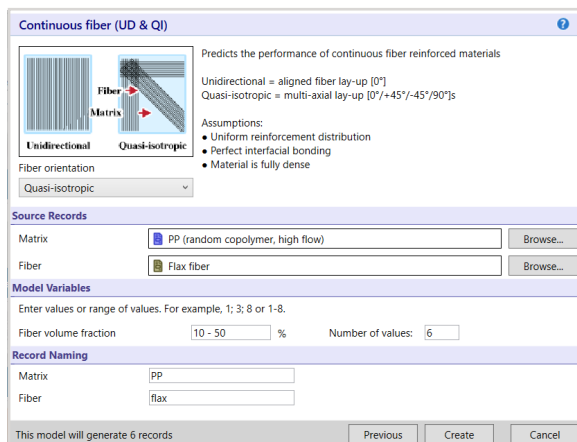
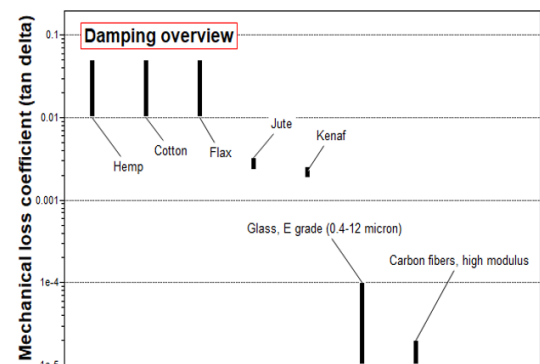
In order to benchmark against typical steel panels, a search for **'automotive door panels'** using the search function of Granta EduPack can be performed. This returns 18 MaterialUniverse records, among these, the **Drawing quality, YS140 (cold rolled)** and the **Dual phase, YS350 (cold rolled)** are good examples of automotive steels. These are marked as Favorite materials with a gold star in the chart above. They are both found under **Drawing quality** in the **Microalloy and high strength steels** folder under **Ferrous Metals and alloys** in the data folder structure. On the chart, reference materials can be marked as Favorites by right-clicking on these records. Using the Favorites tool button (the star) to highlight these makes it easy to compare properties of polymer candidates with the reference materials. Steel and aluminum panels appear hard to beat when it comes to price performance. However, for a fair comparison with polymers and composites, the cost of manufacturing (not just the material cost) would be important to include. This can also be done with the Synthesizer tool mentioned above.

5. The Synthesizer tool



If we want to explore a structural hybrid or a composite that is not among the around 4000 materials already present in MaterialUniverse, we can do this by using the Synthesizer tool as shown on the left. The tool contains models to estimate some key properties of cellular structures, simple bound composites, sandwich structures and multi-layer materials. Moreover, we can explore the economics of manufacturing components, including estimates of different manufacturing costs. To illustrate how Granta EduPack can be used to improve products, we will explore a composite for the Smart door panel consisting of a PP matrix reinforced with flax fibers.

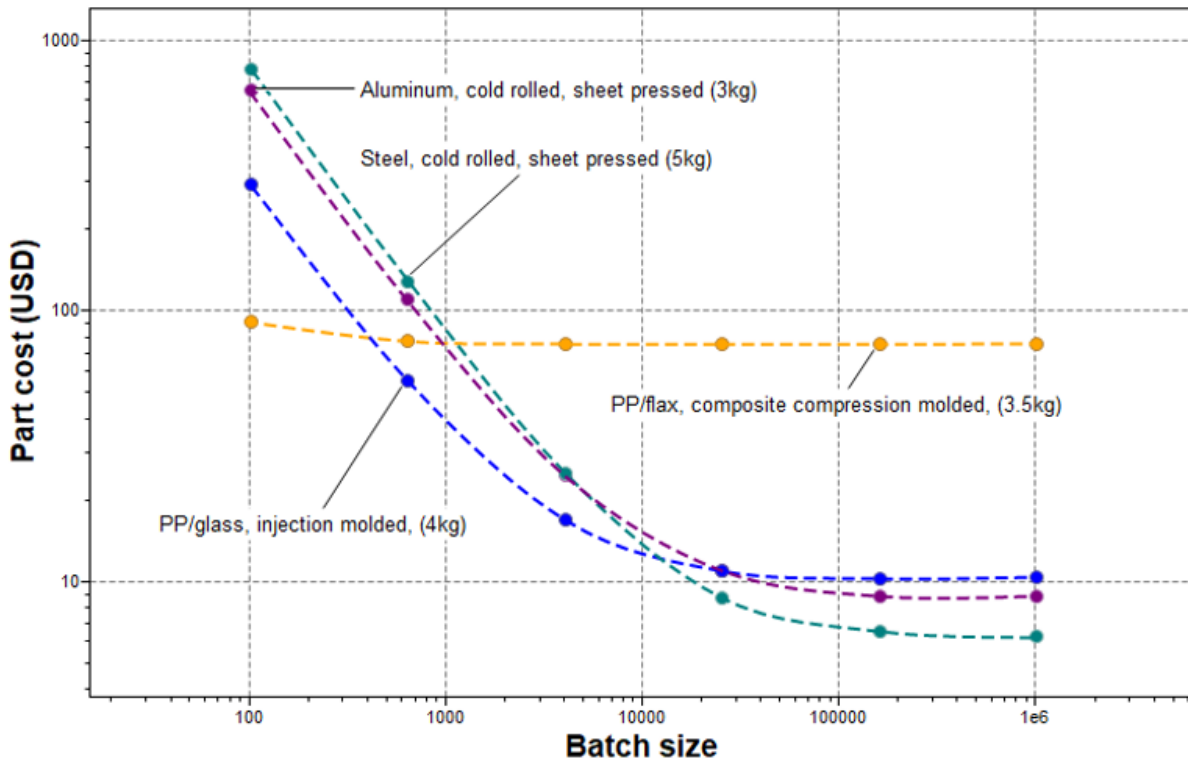
Flax reinforced polymers have recently been marketed for motorbike fairings and sports canoes, for example, *Biotex Flax* from Composites Evolution. There are, however some additional reasons why this composite might be of interest for a lightweight concept car. Flax is often used as a sustainable (renewable) fiber material and it has excellent damping properties, useful to reduce vibrations and noise in a door panel. To create this virtual material, we click on *Continuous fiber (UD&QI)* which is listed under **Composites (Simple Bounds)** in the figure above. A window pops up (shown below to the left) and we fill in the chosen values. By clicking on *Create*, the records of our better material (orange in the right figure) are generated.



When investigating this synthesized hybrid material, the so-called **Part Cost Estimator** quickly estimates the cost to manufacture a component and compare different classes of materials and processing routes. Thus, not only the cost of the materials is considered but the combination of materials and manufacturing.

To the right, our choice of the parameters that must be filled in are displayed. Along with the material and the part's mass and length (approximation), the batch size and the primary and secondary (optional) processing parameters are specified. The resulting data records from the part cost estimator are displayed on the graph below; Flax fiber reinforced composite compression molded Polypropylene (created with the Synthesizer tool), 30% Glass fiber reinforced injection molded Polypropylene, as well as Steel and Aluminum, both cold rolled and sheet press formed. The value for scrap is set to 10% for the metals and 0 for composites.

At a batch size of 100, the PP composite are cheaper than Steel and Aluminum per item. The part cost for the flax composite (orange) is lower than for PP/glass (blue) up to a batch size of a few hundred. The cost of all four materials decreases as the batch size increases due to a fixed tooling cost. At a batch size of about 10 000, the part cost of Steel falls below the PP composite and just after that, Aluminum follows. The part cost for the four materials eventually flattens out and remains constant near their material cost, Steel being lowest. For small series, the PP composites remain the most economic option.



6. Analysis and reality check

Traditional approaches to materials selection often rely on previously used materials, on an engineer's experience or that of a colleague or supplier. This can work. But does it give you a result that is repeatable, auditable, or the best for the application? For applications with multiple requirements and complex selection criteria, such choices may not be optimal. The lack of a systematic rationale for the decision may also cause problems if the design is audited, or when it needs to be refined. A suitable material will meet the constraints whilst maximizing or minimizing the objectives.



For a small batch size (production series), Glass fiber filled PP (or our synthesized PP/Flax composite) seems to be the most adequate polymer option for the application of car door panels. This is relatively close to the actual polymer chosen for the Smart car depicted to the left. A PP material was indeed developed by Borealis, for door panels. This is a 20% mineral filled grade (Talc), which perhaps was chosen for a better surface finish or manufacturing properties than fiber filled PP. Surface finish, of course, is a very important attribute that must be considered in the selection process.

The **Smart ForTwo** has become the first series-manufactured automobile to use body panels entirely of polypropylene (PP). To make the parts, Smart's supplier **Plastal** [4] uses the newly developed thermoplastic polyolefin composite (TPO) "Daplen ED230HP" from Borealis [5]. A slightly different version of the polymer is already being used in the tailgate of the Renault Modus and in the tailgate lining of the **Citroën C2**.

7. What does Granta EduPack bring to the understanding?

In this case, Granta EduPack was able to provide overview and performance charts that helps the educator to discuss important differences between engineering materials. It enables a discussion about pros and cons of new polymer and composite alternatives to steel alloys and also showed why steel is the main material used, based on cost estimates. The synthesizer tool facilitated exploration into composites and renewable fiber reinforcements and enabled comparisons of costs for different manufacturing processes and batch sizes.

Granta EduPack helps suggest the following conclusions:

- The rational materials: Al, and PP composites all compare favorably to the steel reference materials with regards to mass performance but have considerably higher cost for large series.
- Glass fiber-filled polypropylene copolymer is the best light and cheap option for polymers, but FEA calculations are needed to more accurately estimate the total weight reduction.
- Flax fiber reinforced PP, a virtually created material, is only cheaper than glass fiber reinforced PP for very small series (up to a few hundred) and would also require FEA calculations for accuracy.

The MaterialUniverse database used so far provides generic material property data, enabling identification of the best materials options from the full range of possibilities. The next step may be to use a specialized database, that gives more detailed information about specific manufacturer's grade

References

1. For example, in Ashby, M.F. (2016) "Materials Selection in Mechanical Design", 5th edition, Butterworth Heinemann, Oxford, UK. ISBN 978-0-08-100599-6.
2. Press release from polymer manufacturers: <http://www.plasteurope.com/news/detail.asp?id=2095>
3. Steel materials for car doors: <http://www.autosteel.org/~media/Files/Autosteel/Great%20Designs%20in%20Steel/GDIS%202005/23%20-%20New%20Steel%20Materials%20for%20Doors.pdf>
4. See Plastal home page: www.plastal.com
5. See Borealis home page: www.borealisgroup.com

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