ADVANCED INDUSTRIAL CASE STUDIES

Automotive Door Panels

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Summary

CES EduPack provides a rational and systematic approach to materials selection which is invaluable to engineering and design. It enables informed materials choice while clearly showing the steps of the process for the purpose of teaching and training. The more realistic the case study, the better it is. Here we focus on a selection and benchmarking example for *polymer door panels*, to replace steel ones 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.

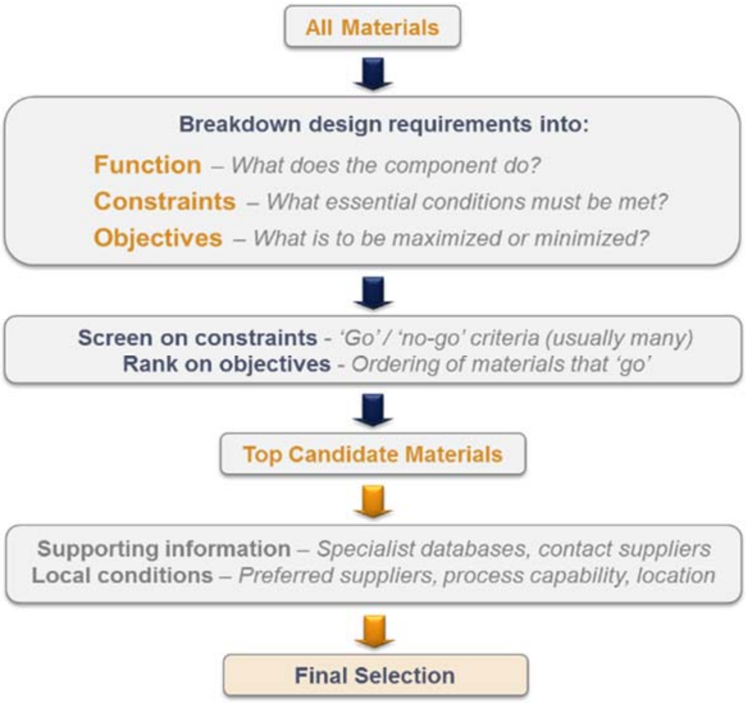
In this case study, we have investigated the lightweighting of an automotive exterior door panel. Inspired by the plastic panels in the ***Smart ForTwo*** car, we studied the suitability of this class of material as a replacement for steel. The selection procedure is described in detail and the result is then compared with the actual material used in the car.

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 Terephtalates 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 CES EduPack.

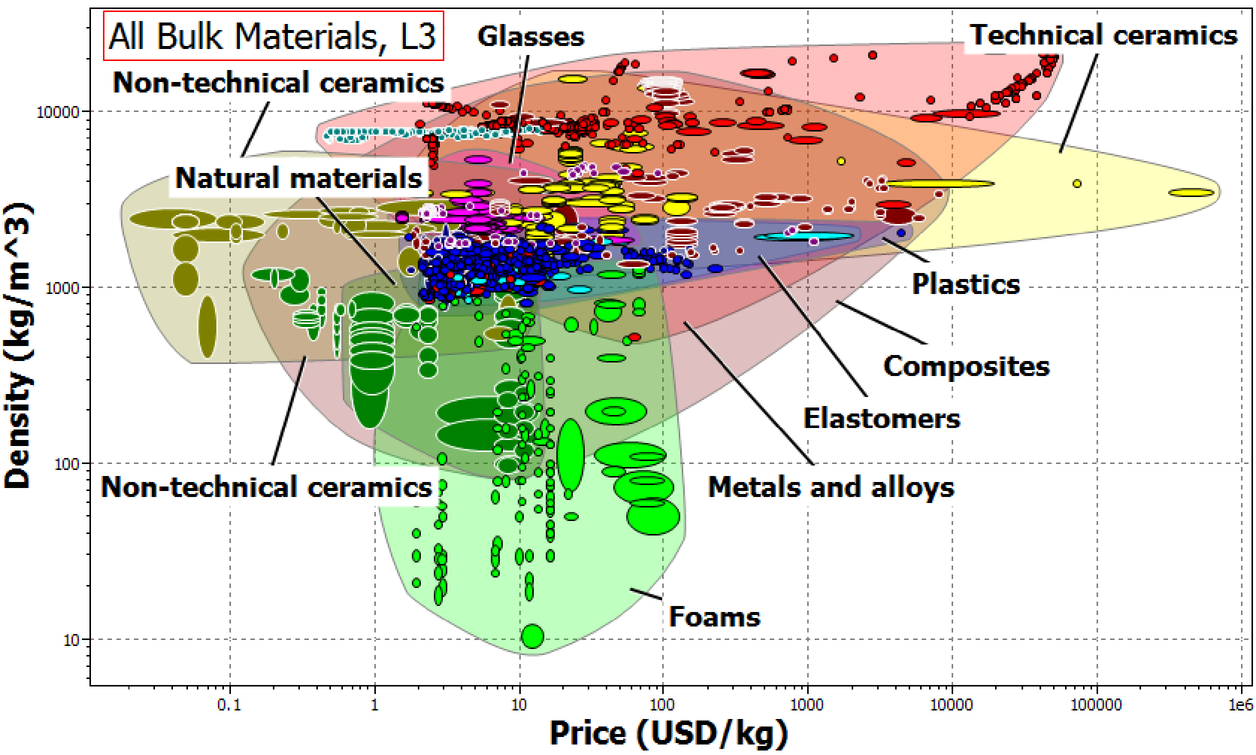
2. How to tackle the problem

CES 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 education. Below is a schematic description of a typical design process.



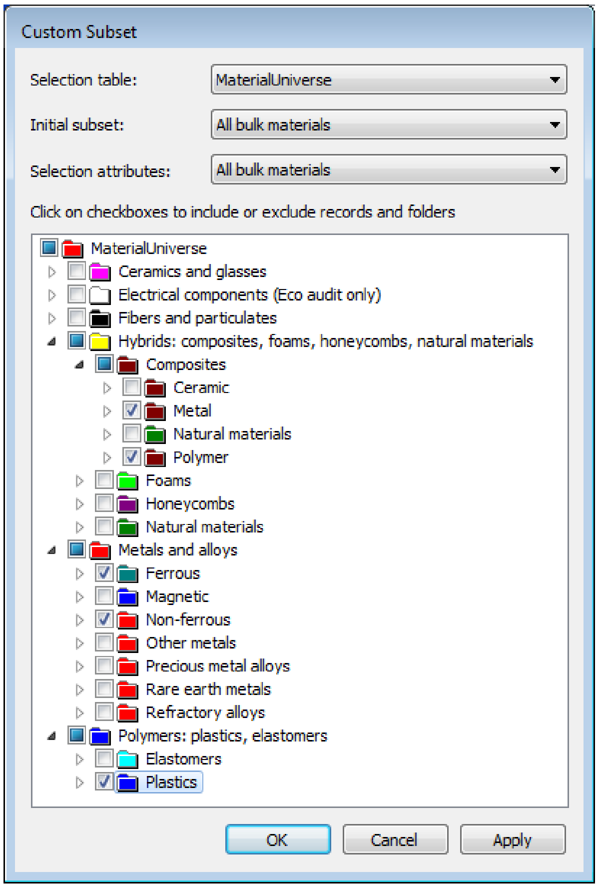
3. How to use CES EduPack to perform materials selection

The basis of the selection is the data records for nearly 4000 engineering materials available in Level 3 of the CES EduPack. These are not all candidates for the door panel, for example, Ceramic materials are too brittle while foams, fibres and particulates are structurally unsuitable. A better starting point for the selection if we want to consider a realistic and, initially an open-ended investigation, would be all metal alloys in the ferrous (steels) and non-ferrous (light metals) data folders as well as thermoplastic polymers and composites. These can be included in a user defined (define your own) subset. A property chart of ***All bulk materials*** at Level 3 is shown in the chart below. It justifies the restricted subset by showing the properties of some 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. The chart can be created using a ***Custom*** subset of the MaterialUniverse data set, using "Create your own subset…" avoiding the unsuitable materials, as discussed above. The resulting chart is seen on the next page.



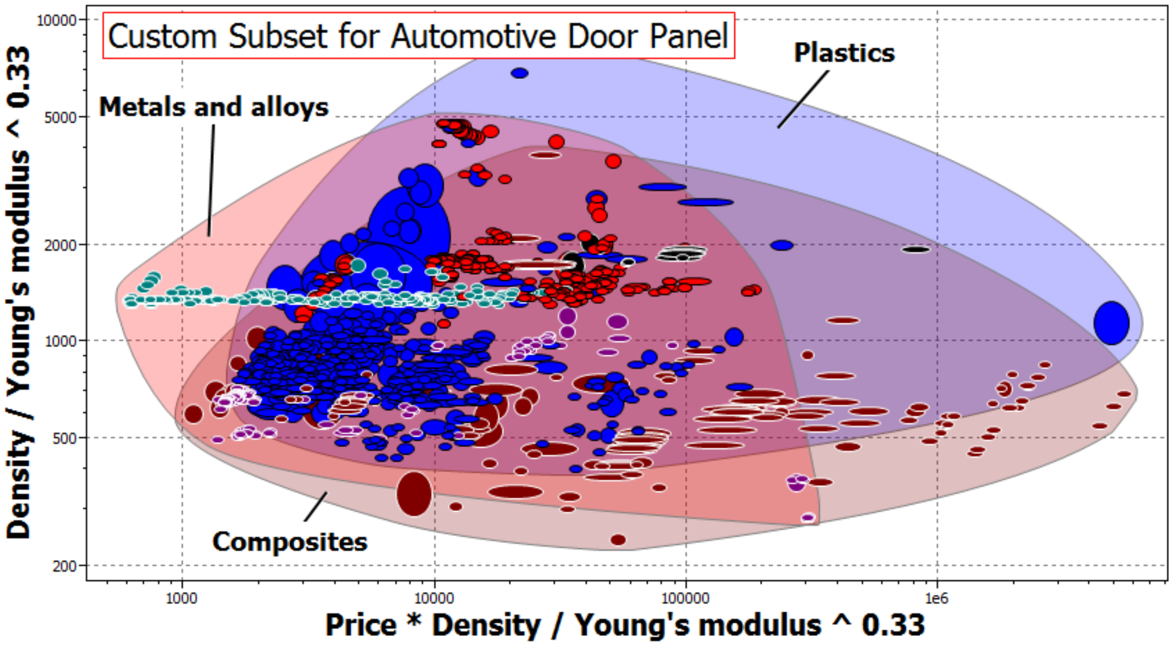
Constraints:

In the CES EduPack software, we begin selection by screening 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

- *Temperature resistance (-15°C to +90°C)*
- *Adequate Yield strength > 22.4MPa*
- *Fracture toughness >1.17MPam^0.5*
- *Resistant to (acceptable/excellent): rain, petrol (organic solvents)*
- *Manufactured by composite forming, flat sheet or molding processes*

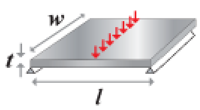
The Custom Subset and Objectives before application of constraints:



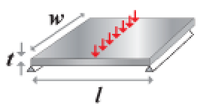
Objectives:

A table of common performance indices can be found under the ***CES Help*** button embedded in the main toolbar of the software. For ***low cost*** and ***low weight*** in a stiffness-limited design, we need to minimize: M1= $\rho / E^{1/3}$ (mass) and: M2= $C_m\rho / E^{1/3}$ (Cost). These are plotted on the Y-axis and X-axis, respectively (see above). In order to search for low values, it is convenient to look at materials towards the origin of the property chart, this is why we chose to *Minimize* the performance indices (see tables below).

Stiffness-limited design at minimum mass

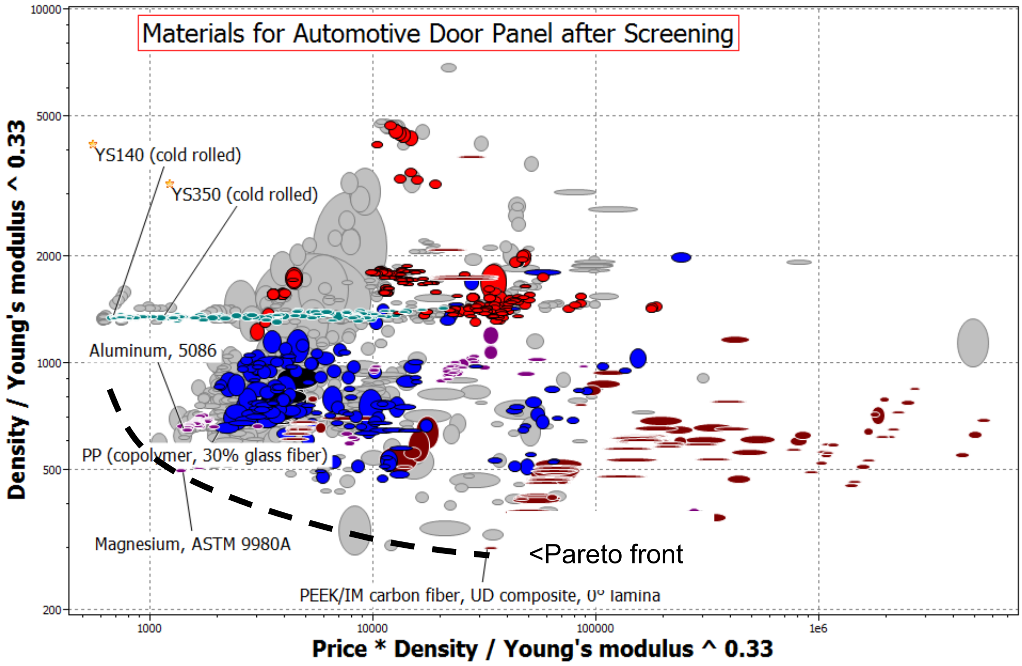
FUNCTION AND CONSTRAINTS[1]			MAXIMIZE[2]	MINIMIZE[2]
Panel in bending		length, width fixed; thickness free	$E_f^{1/3} / \rho$	$\rho / E_f^{1/3}$

Stiffness-limited design at minimum cost

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

Result:

The resulting chart after materials are screened away (grey), with objectives on the axes, is shown below:



4. Trade-off and benchmarking

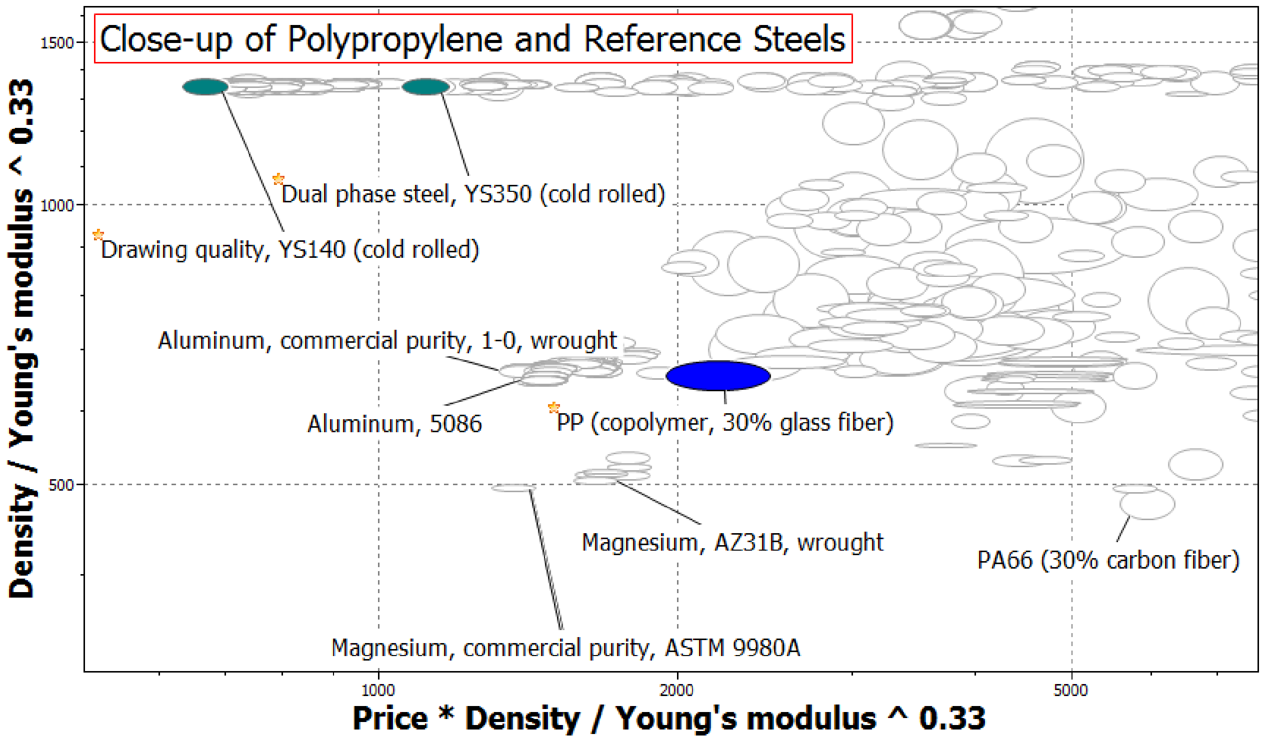
Among the remaining materials in the property chart, the 'best' ones are those along the Pareto front, which is a boundary line that can be imagined at the lower left edge of the bubbles (dashed line). We can see by the colour coding that all types of materials, thermoplastics, composites, ferrous and non-ferrous metal alloys are near this front, which represents a trade-off line. Plausible candidates are lightweight metal alloys, aluminium and magnesium, as indicated in the chart above. Polymers (in blue) are attractive materials comparable to aluminium if lightweighting is important. Composite materials (in red) are favourable if lightweight is very important and cost is not so much of an issue.

In order to benchmark against typical steel panels, a search for '***automotive door panels'*** using the search function of CES 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 steel. These are marked as reference materials with a gold star in the chart above. They are both found 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 ***Favourites*** by right-clicking on these records. Using the Favourites tool button and highlights these makes it easy to compare properties of polymers with the reference materials. Steel and aluminium panels are hard to beat when it comes to price performance.

5. 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 maximising or minimizing the objectives.

A number of light metals, aluminum and magnesium have better mass performance than the steels. Among the plastics, polypropylene (PP) filled with 30% glass fiber appears the best. This is very close to the actual polymer chosen for the ***Smart*** car depicted on the cover. A PP material has indeed been developed by Borealis, for door panels. This is a 20% mineral filled grade (Talc), which was chosen since they give a better surface finish than glass fiber filled PP. Surface finish, of course, is a very important aesthetic attribute that may 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** (Kungälv, Sweden; www.plastal.com) uses the newly developed thermoplastic polyolefin composite (TPO) "Daplen ED230HP" from **Borealis** (Vienna, Austria; www.borealisgroup.com). A slightly different version of the composite is already being used in the tailgate of the ***Renault Modus*** and in the tailgate lining of the ***Citroën C2***.

6. What does CES EduPack bring to the understanding?

CES EduPack produces quantitative and highly visual results interactively which, combined with the materials expertise of an educator, can help to teach the design process and how to make good materials decisions.

CES EduPack helps suggest the following conclusions:

- The rational materials: Al, Mg, CFRP and PP all compare favorably to the steel reference materials with regards to mass performance.
- Glass fiber-filled polypropylene copolymer is the best light and cheap option for polymers, but FEA calculations are needed to estimate the total weight reduction.
- PEEK carbon fiber composites (e.g. Endolign) had been considered, and would give a substantial bulk reduction compared to unfilled PEEK. This appears to be a very costly option, though.

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, such as CAMPUS Plastics, that gives more detailed information about specific manufacturer's grade

References

1. For example, in Ashby, M.F. (2005) "Materials Selection in Mechanical Design", 3nd edition, Butterworth Heinemann, Oxford, UK. ISBN 0-7506-6168-2.

2. Press release from polymer manufacturers: http://www.plasteurope.com/news/detail.asp?id=2095

