Granta white paper

Optimizing Materials Strategy – Can you afford not to?
A new approach to materials decisions could be worth $ millions

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Executive summary

To succeed, manufacturing enterprises need to do much more than simply deliver products that excel at their required function. They must meet wider product design objectives that allow them to address strategic drivers such as cost, environmental legislation, and global manufacturing. Materials decisions are central to these objectives. Sustainable success requires strategies that ensure these decisions are optimized not just for individual designers, but also across the enterprise. The right materials strategy, effectively implemented, can be worth millions of dollars.

But defining and implementing such strategies can be very difficult for a typical manufacturing organization with products that use many different materials and support many applications, with operations split across many businesses or sites, and with those operations further complicated by the impact of new regulations in areas such as the environment, health, and safety.

This paper outlines an innovative approach that is being applied to address these challenges. It makes materials decisions more systematic by applying powerful techniques and software tools to capture and analyze critical materials information, and deploy the resulting ‘business rules’ to those involved in making materials decisions. The tools consider the implications of cost – whether material purchase cost or environmental cost – alongside functional requirements. And, crucially, they are delivered within a framework that helps to ensure consistency in decision-making across the enterprise, bridging between Design and Procurement goals to enhance the execution of both.

The paper begins by discussing why, and how, materials strategies could be improved in most manufacturing organizations. It then considers three categories of application where an approach such as that outlined above can help: optimized materials selection, cost avoidance through materials rationalization, and a systematic approach to eco design. A case study showing the potential multi-million dollar impact is included.

The paper then explains the technology behind the Granta solution – combining the pioneering methodology of Professor Mike Ashby’s materials performance indices with the ability to assemble the necessary materials data and to deploy the resulting strategies enterprise-wide.

Finally, the paper reviews the considerations involved in implementing a solution. A collaborative industry project, the Materials Strategy Consortium, offers one route. This provides the opportunity to benefit from shared experience from industry peers and the ability to have formal input into the future development of the underlying technology – leveraging collaborative shared funding of new developments and getting particularly cost-effective access to the software itself.
1. What is an integrated materials strategy?

1.1 Considering both function and cost in materials decisions

By ‘materials strategy’ we mean a systematic approach and supporting information technology that guides and enables materials decisions for all of an organization’s designers and engineers. The impact can be tens of millions of dollars.

Business success, sometimes even business survival, is no longer guaranteed simply by delivering products that excel at their required function. Cost must be minimized. Products must be rendered more attractive, portable, or usable by making them smaller and lighter. The impact on the environment and on health and safety must comply with regulations.

Market trends make it ever harder to meet this diverse set of design objectives (Figure 1). Globalization increases cost pressures and at the same time means products must meet consumer demands, regulations, and local manufacturing challenges in more markets. New regulations place more demands on energy usage, carbon footprint, and end-of-life properties. Customers want greener, smaller, lighter, and cheaper products.

In designing a product or component, three fundamental decisions are made – the choice of material(s), the choice of shape, and the choice of manufacturing process(es). The consequences of these choices throughout the product’s entire life cycle must be understood. To do this while meeting many, often conflicting, objectives, engineers need the right information and the right decision support tools.

Their companies therefore make major investments in design, simulation, and other product life cycle software - but the emphasis is invariably on defining product shape, and on optimizing the manufacturing process. While simulation software can readily analyze the behavior of a user-specified material in a design, few PLM tools systematically aid materials decisions, especially from a cost perspective – despite the fact that material choice invariably has the most profound effect on the objectives in Figure 1. Such tools as do exist are typically based on ‘catalog’ databases, and at best may assist with individual materials selection decisions – with the potential to save perhaps tens of thousands of dollars. In this paper we explore the concept of an integrated materials strategy that helps guide all materials decisions – with a potential impact of tens of millions of dollars.

<table>
<thead>
<tr>
<th>Increasing strategic pressures</th>
<th>Product design objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumer demands</td>
<td>Deliver required product function</td>
</tr>
<tr>
<td>Competition</td>
<td>Minimize cost</td>
</tr>
<tr>
<td>Regulation (REACH, EuP…)</td>
<td>Reduce environmental impact</td>
</tr>
<tr>
<td>Globalization (low cost manufacture)</td>
<td>Make it smaller, lighter</td>
</tr>
<tr>
<td></td>
<td>Meet health &amp; safety regulations</td>
</tr>
<tr>
<td></td>
<td>Enable global manufacturing</td>
</tr>
</tbody>
</table>

Figure 1. Product function is not enough! Typical product design objectives and some of the strategic drivers that make them increasingly important to business success
By ‘materials strategy’ we mean a systematic approach and supporting information technology that can be deployed on an enterprise level – enabling consistent consideration of both functional performance and lifecycle cost implications, by all of an organization’s designers and engineers. The goal is to optimize product performance against objectives such as cost across the company’s portfolio. The results are both better individual design decisions (valuable from an engineering perspective), and opportunities for rationalization and economies of scale (valuable from a purchasing/supply chain perspective).

An integrated materials strategy can help any manufacturing organization seeking to address the strategic drivers and design objectives outlined above – but it is particularly beneficial where enterprises have:

- Multiple sites, each with their own suppliers and practices – for example, due to growth by merger and acquisition
- Large and complex product ranges, requiring many materials decisions
- Globally-distributed manufacturing and/or material procurement, requiring use of local equivalent materials
- Frequent, rapid design cycles (requiring many decisions) or, conversely, lengthy design cycles (where significant expense is committed early)

Relevant industry sectors include manufacturers of: general industrial components; automotive parts; aerospace components and systems; domestic appliances and equipment; tools; and heating, ventilation, and air conditioning equipment.

### 1.2 What’s so important about materials decisions?

Let us begin by exploring why materials decisions are so pivotal to achieving product design objectives. Table 1 outlines some of the key ‘functional’ requirements placed on materials during product design. Existing approaches and tools for materials decision-making focus almost exclusively on meeting such functional objectives.

Designers working in industries where safety or quality are paramount will also be familiar with the constraints imposed by standards, legislation, or other regulatory requirements, as illustrated in Table 2. Such constraints are becoming increasingly familiar across all of manufacturing industry as new eco regulations begin to have an impact.

#### Table 1. Functional requirements on materials

Materials must meet / exceed design specifications for:

- Stress from static or dynamic loads
- Fatigue from cyclic loading
- Extended periods under load, i.e., creep resistance
- High and/or low service temperatures
- Thermal conductivity or insulation requirements
- Electrical conductivity or resistance requirements
- Sustained operation in chemical environments
- Etc.

#### Table 2. Regulations or standards that constrain materials options

<table>
<thead>
<tr>
<th>Area</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>All industries – eco regulations</td>
<td>REACH, EuP, RoHS, WEEE</td>
</tr>
<tr>
<td>Medical devices and supplies</td>
<td>ISO 10993, USP class VI</td>
</tr>
<tr>
<td>Food and drinking water contact products</td>
<td>FDA, EU, NSF, other food contact regs</td>
</tr>
<tr>
<td>Thermal or fire resistant products</td>
<td>UL 94 flame ratings, UL 746 relative thermal index</td>
</tr>
<tr>
<td>Aerospace and defense</td>
<td>ITAR</td>
</tr>
<tr>
<td>Oil/gas/process and nuclear industries</td>
<td>ASME boiler &amp; pressure vessel code</td>
</tr>
</tbody>
</table>

Fulfilling functional requirements while meeting any relevant constraints can be a challenging task. Nevertheless, we would expect competent designers and manufacturing organizations to have this process broadly under control – and we will also present software tools that can help. The real complexity comes when trying to combine these requirements with the over-arching product design objectives in Figure 1. The importance of materials to these wider objectives is itemized in Table 3.

Together, Tables 1, 2 and 3 show that materials have a fundamental impact on product design – and that optimizing that impact across the enterprise and its products will be a complex business! In this paper we will present a systematic means of addressing this complexity.
<table>
<thead>
<tr>
<th>Product design objective</th>
<th>Relevance and impact</th>
<th>Significance of materials decisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimize cost of product up to point of sale</td>
<td>This is the fundamental objective in most product manufacturing – it directly impacts profitability</td>
<td>Need to meet functional requirements, but consider:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Cost of manufacturing processes required by materials choice: shaping, joining, surface treatment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Cost of transportation (related to material weight)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dependencies include:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Volume of manufacture</td>
</tr>
<tr>
<td>Minimize cost of product over its whole lifecycle</td>
<td>Eco regulations and energy costs are increasing customer focus on the ‘full life performance’ of products. Examples:</td>
<td>Need to consider all of the above, plus costs of:</td>
</tr>
<tr>
<td></td>
<td>• Cost of use for energy-using and generating products</td>
<td>• Disposal (consider suitability of material for landfill, recycling, combustion, or incineration)</td>
</tr>
<tr>
<td></td>
<td>• Cost of product disposal (vehicle end of life, electrical and electronic equipment)</td>
<td></td>
</tr>
<tr>
<td>Make it lighter</td>
<td>In moving products, lower mass = lower energy use = lower cost of use (aircraft, automotive, moving parts of any equipment)</td>
<td>Need to meet functional requirements while minimizing mass of material – note, there invariably needs to be a trade-off between product mass and cost</td>
</tr>
<tr>
<td></td>
<td>For portable products, lower mass = higher convenience (laptops, other personal electronics)</td>
<td></td>
</tr>
<tr>
<td>Make it smaller</td>
<td>Size-constrained products: Microsurgery instruments, mobile phones and other personal electronics</td>
<td>Need to meet functional requirements while minimizing volume of material</td>
</tr>
<tr>
<td>Reduce environmental impact</td>
<td>Examples:</td>
<td>Consider the environmental ‘cost’ (e.g. use of energy, water, etc; emission of CO₂ and other wastes) of:</td>
</tr>
<tr>
<td></td>
<td>• Transportation</td>
<td>• Manufacture (formal, joining, surface treatment)</td>
</tr>
<tr>
<td></td>
<td>• Energy using products: boilers, electronic equipment, electrical appliances</td>
<td>• Transportation to market</td>
</tr>
<tr>
<td></td>
<td>• Buildings and civil engineering structures</td>
<td>• Use</td>
</tr>
<tr>
<td></td>
<td>• Any high volume manufactured product</td>
<td>• Disposal</td>
</tr>
<tr>
<td>Enable global manufacturing</td>
<td>Products are often manufactured in (low cost) locations remote from the point of design and sale</td>
<td>Need to understand differences in local materials, standards, and processes and, where appropriate, specify equivalents</td>
</tr>
</tbody>
</table>
2. Where can an integrated materials strategy help me?

2.1 Optimized materials selection

Let us start with the simplest example – the need to choose a material for a specific engineering application. Most often, this choice is based on an engineer’s experience, on the recommendation of a supplier, or simply on what has been used before. In many cases, such approaches work. But they can have some serious drawbacks. They make the organization dependent on individuals’ knowledge that may not always be there. They are not repeatable – i.e., two engineers set the same problem may not arrive at the same conclusion. This is dangerous for any quality-conscious business. Similarly, decisions are not ‘auditable’ – the organization cannot show a customer or regulator the quantitative reasoning behind them. Finally, these approaches inhibit innovation – they do not systematically explore all possibilities that could deliver better results.

So how can software tools enable more rational materials selection? First-generation materials database tools focused on the primary functional requirements (Table 1) and helped to identify a candidate or substitute material on the basis of a simple comparison of composition or property profiles. For example, if an alternative to a grade of 30% glass-fiber-filled PA66 (nylon 66) was required, a search could be undertaken for another grade of the same composition, perhaps from another supplier. Alternatively, a material with a different composition, but a similar property profile, could be considered – for example, 35% glass-filled PBT (polybutylene terephthalate) has similar stiffness and strength properties in this case.

But, as we discussed in Section 1.1, real materials decisions have broader objectives – most frequently, to minimize cost. Simple property or composition comparison methods cannot, for example, identify that it might be possible to specify a cheaper material of different composition and property profile if changes to the design – such as a change in thickness – were also made. Similarly, simple comparisons do not enable evaluation of trade-offs, such as those between cost and weight, or cost and impact resistance.

![Figure 2. Cost of panels of equal stiffness made from different materials. The ‘cost per unit of function’ index plotted here combines data on engineering properties with price data.](image-url)
Material performance for a specific application is thus rarely governed by the individual measured properties in handbooks or manufacturers’ datasheets, but by combinations of properties1. And functional properties must be combined with cost (whether financial cost, environmental cost, or the ‘packaging costs’ of weight or volume). Figure 2, for example, shows the cost of panels of equal stiffness (but variable thickness) for common materials classes. Note how the parameters combine – a panel in bending could be expensive because of the absolute material cost (e.g. PEEK), and/or because it has lower flexural stiffness and a large thickness of it would be required (e.g. Natural Rubber). Many options highlighted by this approach are not so intuitive.

When the ‘cost per unit of function’ is considered using such an objective, unbiased, and systematic analysis, we have established a rational basis to select, specify, and substitute materials. At Fortune Brands Home & Hardware, for example, such an approach assisted a component redesign that cut production costs in half and doubled performance on an important product line2.

However, many manufacturing organizations still do not approach basic materials selection and substitution decisions in this way. So this is the first significant area where an integrated materials strategy can help many businesses. Simply by enabling systematic selection, via a software tool that embodies ‘cost per unit of function’ methods, we can begin to generate complete and auditable answers to real business questions such as those outlined in table 4. However, we are still only talking about better individual decisions. Can we apply similar methods to decision-making enterprise-wide? Is it possible to use these methods to help optimize the aggregate effect of the hundreds of decisions taken across a business?

The answer is ‘yes’. But this requires us to think carefully about how we capture and share optimal approaches to decisions, and how we deliver selection tools to many people in a consistent and easy-to-use manner. The result is a framework that helps answer business challenges such as those in Table 4 across a department, site, or entire organization, that does so in a ‘traceable’ manner (i.e., the analysis and data behind any decision can be traced in full after the fact), and that also helps us to retain corporate materials knowledge. To explore this challenge, we now look in detail at the highly important issue of cost.

### 2.2 Cost avoidance

Considering the impact on cost of the hundreds of materials decisions taken across an enterprise, shows the danger of traditional approaches based on individual experience and ‘using what we have always used’. These make it very difficult to take a holistic view and to ensure that objectives are met for the organization as a whole, rather than simply for one application. They are, for example, likely to result in many different types of material being specified, which may be the optimal choice for each individual design, but may miss the opportunity to create economies of scale for the whole business. The result is likely to be much higher costs than might otherwise be possible.

The other extreme would be if all materials decisions were centralized and analyzed quantitatively. We can quickly dismiss this as likely to be impractical in the vast majority of cases, as well as stifling for innovation. But how do we balance the wish to use individuals’ creativity and experience against the need to optimize with respect to organizational objectives?

Figure 3 (overleaf) shows the three primary options for cost reduction or minimization.

<table>
<thead>
<tr>
<th>Materials selection challenges</th>
<th>Specific answers sought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material cost is a high proportion of our product cost and markets are volatile and inflationary. This threatens our profitability</td>
<td>What are our material and process alternatives? Are we using the most profitable? What are the trends? At what point does it make sense to switch?</td>
</tr>
<tr>
<td>We are experiencing materials failures in our products</td>
<td>What material can we substitute with minimal other changes? What grade offers similar characteristics without failure and without cost penalty? What would be the impact?</td>
</tr>
<tr>
<td>We manufacture in different countries</td>
<td>What substitute material can I buy and use locally? How ‘equivalent’ is it relative to the existing material? What is the impact on quality, cost, consumer experience, or regulatory compliance?</td>
</tr>
<tr>
<td>A vendor has offered us a new material option</td>
<td>How do we evaluate it systematically against existing options? In what products will we gain if we switch?</td>
</tr>
</tbody>
</table>

**Table 4. Some practical materials strategy issues**
Option 1 - Take out cost at the production stage
Companies can try these familiar tactics:

- Negotiate lower costs with suppliers
- Substitute cheaper materials and components
- Use lower-cost manufacturing locations

These approaches can indeed have immediate impact on cost. However, they have some limitations:

- There is an absolute limit to the cheapness of any given material (the bottom of each ‘bar’ in Figure 2). If a lower price is negotiated then, in inflationary times, the vendor will try to ‘re-negotiate’ the price back up. This approach is never going to be a ‘win-win’, as the US auto industry has discovered.

- ‘Drop-in replacements’ of materials – i.e., where a new material can be used to create a component of the same size and shape and using the same tooling – are rare. A cheaper material may imply design changes that are not possible for products already in production. For example, changing from metal to plastic normally implies a thicker or larger-volumed component with different detailing.

- In industries such as aerospace, medical, or semiconductor equipment, substitution can be uneconomical for regulatory, product liability or other reasons. In semiconductor equipment, for example, once a machine is qualified for service (an expensive process), changes are risky. The vendor is damaged if its customer complains of contamination or particle generation in the process.

Option 2 - Materials rationalization or standardization: use fewer materials and suppliers
This is where we see major benefits from implementing integrated materials strategies. If the organization can gather together all of the relevant cost and engineering data, then the ‘cost per unit function’ principles discussed in Section 2.1 can be used to undertake a quantitative examination of the likely product use cases. All potential materials can be categorized in the context of these use cases. Those that are most effective based on the balance of cost and engineering performance for the required functions can be designated ‘preferred’. Designers can then be provided with tools that guide them towards the preferred materials, while not preventing them from using other materials if the application demands it. They can also be shown how each material performs in terms of ‘cost per unit of function’ for a given application. The result should be a balance in which functional requirements are met and innovation enabled while, overall, fewer materials are specified.

There are particular benefits in this approach for companies where different business units have local practices and suppliers. The box on the next page illustrates the potential multi-million dollar savings.

The benefits of materials rationalization are:

- Increased negotiating leverage with suppliers
- Reduced inventories, and thus cost
- It simplifies sourcing of materials in multiple manufacturing locations
- Organizations can build a deeper expertise in a smaller number of materials and processes. This enables faster development at lower cost for the equivalent risk and quality. It is also cheaper to create libraries of material properties for predictive design and CAE.
Case Study: Saving $50m

This case study draws on real examples of projects at major manufacturing organizations and is shared with the permission of those enterprises. Financial and other details have been altered to protect confidentiality.

Company X is a global manufacturer of components and equipment for industrial and consumer use. Like many of its peers, it is composed of disparate individual businesses, each with revenues in the $1bn-$5bn range.

The raw materials budget for a typical $3bn division is $750m per annum. Enterprise-wide, it is $5bn. One division alone uses several hundred different grades of polymer. Growth through acquisition has led to diverse materials policies with little or no rationalization of materials usage across businesses.

At companies like Company X, a corporate materials strategy program might aim to reduce raw material costs by 5 or even 10%, while also improving the quality of materials decisions. A key component of such a program is the definition of a list of ‘preferred materials’ to guide the company’s hundreds of designers towards using fewer and better-performing materials.

This allows the company to develop deeper expertise on a smaller range of materials, to make more cost-effective selection decisions both individually and across the businesses, and in addition to negotiate lower prices with the suppliers of the preferred materials.

Company X has worked with Granta to refine its preferred materials approach and to develop tools that help to roll it out to the corporation - providing designers with practical help in making materials choices, while also helping enforce a consistent corporate strategy. Granta experts have helped the company to develop databases for key classes of material, ensuring that properties of particular relevance to those materials are included, and that each database covers the full range of materials options with the preferred materials identified as the default subset.

The benefits are compelling. The challenges are:

- Experience and expertise are required in striking the balance of which materials and suppliers to designate ‘preferred’?

- ‘Immediate’ rationalization is only normally possible where a material can be replaced by a very similar material from a preferred supplier. As already noted, other types of ‘drop in’ replacement are hard to achieve without redesign – as discussed below.

Option 3 – ‘Design out’ cost

The design of a next generation of products provides the best opportunity to get rid of cost. The same materials strategy improvements discussed under Option 2 can be applied here, but with even greater results, since this is the point at which materials rationalization can be ‘built in’ with greatest ease and the most impact. It is also easier to specify cheaper materials, since components and tooling can be designed to take advantage of alternatives.
Summary
Integrated materials strategies for enterprise-wide cost optimization focus on materials rationalization and designing out cost. These strategies can be improved by assembling comprehensive data on the likely candidate materials and providing tools to enable expert selection and analysis based on ‘cost per unit of function’. A system is then needed to help designers apply the results of this analysis enterprise wide, for example, through a ‘preferred materials’ approach.

2.3 A systematic approach to eco design
In the previous discussion, ‘cost’ meant ‘financial cost’. But the same principles can be applied to ‘environmental costs’ such as energy or CO₂ footprint. Eco design is another, increasingly significant, area in which an integrated materials strategy provides benefits.

Tables 2 and 3 showed the increasing importance of constraints imposed by environmental legislation and the growing focus on ‘eco design’. These have fundamental implications for the materials specified in product designs. Companies increasingly need to design to ensure compliance with, for example, restricted substances legislation. This is not simply a question of omitting currently restricted substances from their design – the companies may, for example, wish to track those materials that might be banned in future, or those where cost or availability may change because a restriction on some element of their processing or use will make them less economically viable to produce. As with our previous case, there will be a need to balance these considerations against other benefits or costs arising from any required changes – in terms of product marketing, financial cost, and performance.

A process similar to that outlined in the case of materials rationalization above could help. First, gather the relevant data (which, here, will include information on restricted substances). Then analyze it to create guidance for designers. Finally, deploy simple-to-use tools that help designers to apply that guidance – perhaps flagging up materials that may be risky and proposing substitutes, ranked according to their ‘cost per unit function’ performance for the application.

Another area of growing importance in the environmental context is design for low energy usage or low carbon footprint. Again, quantitative analysis based on materials property data can be used to develop strategies that can then be deployed to designers. In eco design in particular, it is important to consider the phases of a product’s life – systematic selection of materials to meet environmental objectives starts by identifying which phase causes greatest concern: production, manufacture, use, or disposal. ‘Eco audit’ software is now available to assist this process. This takes as input information on the materials and processes that make up a product and on its transport and use. It then combines this with eco-property data that specifies, for example, how much energy or CO₂ is associated with generating a kg of the raw material. The result is a plot (Figure 5) that shows the relevant impact of each phase in the product’s life.

This information can then be used to guide design. If, for example, material production is the dominant phase, selection aims to minimize production energy or associated CO₂ emissions. If the use-phase dominates, selection might focus instead on low weight, or excellence as a thermal insulator or electrical conductor. Designers could be provided with such guidance and access to an Eco Audit Tool to quickly compute the likely impact of changes in materials. They could then also use the approach outlined in Section 2.2 to explore the impact of these changes on cost and other strategic factors.

However, implementing such an approach requires both property data for the eco attributes of materials, and consideration of these in combination with data for the functional performance of the design. Few designers today can readily find reliable eco property data, or methods for using it. But this is a fast-growing area – for example, the Environmental Materials Information Technology (EMIT) Consortium is a project focused on developing eco property data sets and software tools to address this emerging need. Here, as in other areas, the technology is now becoming available to implement the sort of integrated materials strategies we have been discussing. We shall next discuss these advances, and available technologies, in more detail.
3. An established software solution

3.1 Solution components

In the above scenarios, the following paradigm emerged as the sequence for deployment of integrated materials strategies:

1. Assemble all necessary materials information (engineering property data, prices, eco-properties…) in one place – this requires both suitable data, and an information system with which to capture, analyze, and deploy the data.

2. Perform the analysis using specialist tools embodying ‘cost per unit of function’ principles to develop strategies or ‘business rules’ that can be used to guide designers.

3. Deploy this guidance via easy-to-use tools, enabling designers to make decisions and answer design questions in the context of the corporate strategy.

In the following sections, we outline a solution from Granta Design that uses commercial off the shelf (COTS) software to deliver each of the above elements of an integrated materials strategy deployment.

3.2 Materials data management platform

The first step is to assemble the necessary data, requiring a system capable of capturing and managing specialist materials data, with supporting tools to enable its deployment and use enterprise-wide. This enables the materials strategy to be based on a complete, coherent, usable body of relevant technical, economic, and environmental property data.

Granta provides such a platform with its GRANTA MI® software, developed in collaboration with the Material Data Management Consortium specifically for enterprise materials information management – the benefits of which have been documented in a companion white paper.

At the heart of GRANTA MI is a database designed to store materials property data. Companies can combine and enrich data from in-house testing and research, proprietary sources, and external references. Materials experts use GRANTA MI’s software tools to manage, analyze, certify, and maintain data, publishing it in a secure and controlled manner. Designers and other engineers can then access and apply this information easily within their routine workflows, assured that it is relevant, traceable, and the best available.

There are a number of factors that make GRANTA MI an obvious foundation platform for an integrated materials strategy deployment:

- Every aspect of the system was designed to cater for highly specialized and complex materials information – for example, handling the multi-dimensional data and specialist units needed to describe the variation of properties with temperature, time, etc.

- The system is designed for enterprise deployment with: a client-server architecture accessed via a web browser; scalability to hundreds or thousands of users; and comprehensive systems of access control (‘who’s authorized to see what’) and version control (for managing changing data).

- It’s where the enterprise already stores its materials engineering information! The materials strategy application can thus leverage existing infrastructure and corporate data.

3.3 Underlying science – The Ashby materials selection methodology

The ability to analyze materials and make trade-offs, particularly when considering combinations of properties such as ‘cost per unit of function’, is at the heart of the materials strategy concept.

The enabling breakthrough in this field, by Cambridge University’s Professor Mike Ashby some 20 years ago, was the formalizing of these property combinations, derived through mathematical analysis of the engineering problem, into materials selection performance indices (Figure 6). Today, along with the familiar graphical means of representing them in order to enable analysis and trade-offs (Figure 7), these performance indices are the accepted core of best practice materials selection. They are at the heart of teaching this subject at over 600 colleges and universities worldwide.

<table>
<thead>
<tr>
<th>Beam in Bending</th>
<th>Objective: Minimise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>Mass</td>
</tr>
<tr>
<td>Stiffness Controlled</td>
<td>$\frac{1}{\sqrt{E}}$</td>
</tr>
<tr>
<td>Strength Controlled</td>
<td>$\frac{1}{\sigma^{0.5}}$</td>
</tr>
</tbody>
</table>

*Figure 6. Performance indices for a beam in bending.*
universities around the world and are applied in industry via the CES Selector software. CES Selector is a simple-to-use PC-based application that draws on databases of materials and processing properties (engineering properties, prices, and eco data) to derive performance indices for objectives input by the user, and present as selection plots such as that shown in Figure 7.

Use of performance indices can lead to surprising results. For instance, one might think that the criterion for the best material for a lightweight plate or panel subject to bending loads is its specific stiffness, i.e., elastic modulus divided by density (E/ρ). In fact it is given by E^\(1/3\)/ρ, while for a beam in bending it is E^\(1/2\)/ρ. These results can have significant implications on material choice. Performance indices for the beam example are shown in Figure 6, and the stiffness-controlled cost index is what was plotted in Figure 2 to show the relative cost per unit of function of candidate materials for this application. Readers familiar with Professor Ashby’s books, or with Granta’s selection software, will know that an extensive range of these indices may be derived – and not only for mechanical design applications.

The Ashby methodology is a key element of a materials strategy solution. For the final element, we present a technology that embodies this capability, while leveraging the GRANTA MI platform to enable enterprise deployment of the resulting strategy.

### 3.4 The Enterprise Materials Optimizer

The Enterprise Materials Optimizer (EMO) is a software module, available through the GRANTA MI web browser interface, which ranks materials for a particular engineering application according to the ‘cost per unit of function’ concept, and which makes it easy to deploy such analysis enterprise-wide. A simple-to-use ‘wizard’ interface (Figure 8) guides the user through the process, starting with specifying the design objective from a set of illustrated options. This might be, to use an earlier example, to ‘minimize the cost’ of a ‘panel loaded in bending’ ‘limited by stiffness’. Users can then specify any additional requirements or constraints, and the system ranks all candidate materials with respect to the overall design objective. Further iterations are simple to explore.

The Enterprise Materials Optimizer also incorporates the preferred materials concept discussed above, and enables this systematic process. The reports produced in response to user input are initially restricted to ‘preferred materials’ that have been centrally defined. Only if none of these are suitable, is the user invited to consider the next (usually more expensive) category of materials in the preferred hierarchy.
A number of the use cases for this approach involve considering options for substitution of a known material. For example, a manufacturer may wish to replace an existing material with a cheaper one, one that is easier to procure, or one that passes new environmental regulations. Such use cases are supported by the Enterprise Materials Optimizer’s reference material capability. Chosen by the user, this reference material appears in all ranked materials lists, pass/fail reports, and graphical illustrations of material performance – and the performance indices of all candidate materials are automatically normalized against that of the reference.

The real power of the Enterprise Materials Optimizer for materials strategy lies in the fact that the ‘wizard’ in which the user specifies their design objectives, and the calculations and preferred material classifications underlying it, can be readily configured by the user’s company. This enables the company to follow the
process shown in Figure 9, in which:

- The functions of the various products are analyzed and categorized by the company’s materials, process and manufacturing experts

- The preferred materials classification is established by considering ‘cost per unit function’ and other related techniques (specific details are typically proprietary, representing company knowledge of how to best exploit materials in their products) and aggregating across the various applications. This exercise alone can enable significant savings from material and supplier rationalization

- The resulting categorization is exposed to designers and engineers via the Enterprise Materials Optimizer’s web browser interface. The ‘wizard’ approach prompts the engineer in the specification of requirements, ensuring all pertinent factors are considered

- In response to these user inputs, the software applies the business rules to identify preferred materials that best fit the company’s strategy for that particular class of application, and ranks them according to relative combinations of performance and cost

Final rigorous analysis and selection is, of course, carried out by the engineer. But in presenting a systematic, objective process for compiling and ranking candidates, throughout the enterprise, the results are more consistent and more traceable design decisions.

3.5 Integration with existing IT infrastructure

Since materials strategy is all about applying materials information technologies to support and enable business success, a final consideration is integration with companies’ wider business systems. Today’s virtual product development process involves the creation, management, and updating of numerical models that represent a component (or assembly of components) at each stage of its lifecycle – from conceptual design, through manufacture, to support and maintenance in use. Even before a single piece of metal has been cut (but once the materials have been selected, recalling the point in Section 1.1), engineers are able to answer the questions ‘What does the component look like?’, ‘Will it perform the function required of it without failing?’, ‘How can it be manufactured and assembled with its fellow components to make the overall product?’, ‘What are the total amounts of materials x, y and z in each of 3 assembled product configurations?’

The resulting Product Lifecycle Management (PLM) infrastructure features a variety of software technologies, and engineering and business tools, that form the engineering IT backbone of the company’s operation. Recalling that the choice of material is one of three fundamental design decisions (the others being choice of shape and manufacturing method), two key questions are invariably asked by IT Departments.

Figure 10. A materials information system needs to interact with many other systems and functions in the engineering information infrastructure
1. Having invested so much in product data management (PDM), enterprise resource planning (ERP) and other corporate data management tools, can’t they manage my materials data too?

The answer to that question is almost always ‘No’, for the reasons discussed in Section 3.2 – materials information systems like GRANTA MI are designed specifically to accommodate the specialist and complex nature of materials information. This involves not only the types of attributes (graphs, matrices, units, etc.), but the granularity of materials records – each material may be defined by 50 or 100 attributes, many with individual updating cycles and versions to track, and there may be several hundred materials in the system.

This is simply not the type of information that a system for managing a company’s overall product model data is designed for. Nor do the personnel administering the product data system have the remit, or the interest, to manage this type of specialist reference resource.

2. Can the materials information system be integrated with my other enterprise IT tools?

This time the answer needs to be ‘Yes’ – a corporate materials information system cannot be an ‘island’, and for maximum benefit needs to be integrated in the greater engineering information infrastructure (Figure 10). In the case of the Granta software, an application programming interface (API) and ‘plug-in’ technology that uses the industry-standard web-services approach enable data to be accessed by other programs.

4. How do I get started?

So how does an engineering organization implement an integrated materials strategy approach?

4.1 Phased implementation – low risk steps

Almost by definition, since the approach will enable new insights concerning how materials are specified, the experience of deploying and using it will suggest new applications. Starting with a pilot implementation of clearly defined scope should offer quantifiable benefits and timely return on investment, while also providing the experience base for future expansion.

An initial priority focus area will probably already be apparent to your business. It may be a cost problem in a particular materials class, the need to adhere to a new environmental regulation, or one of the other drivers outlined in the introductory sections. The next step involves scoping the initial implementation. Should the pilot be for a particular site, product line, or perhaps new business initiative? Who are the principal stakeholders? (Typically these are the materials experts who will be maintaining the data, decision-makers in Design, Engineering and/or Purchasing who will be using the data, and IT personnel who will be administering the system.)

Where there is a compelling business need, these questions can be answered fairly readily. If required, Granta has a formal Requirements Definition Analysis process, designed to help scope out how to proceed.

4.2 Got data?

The key to any decision support system is, of course, the data – and thus the knowledge – contained within it. There are many criteria that determine whether data is actually useful and fit for purpose – breadth, depth, auditability, applicability to the decisions that need to be made, precision, units, presentation format, frequency of updating, structure for efficient searching, structure for efficient access by other computer programs. But data that is applicable and fit for purpose is certainly required!

There can be three primary sources for the data that underpins a materials strategy solution:

- Off-the-shelf reference data
- Suitable in-house data that already exists in electronic format – local databases, Excel spreadsheets, etc.
- A full in-house materials data management environment, created with Granta’s data capture tools, linked to testing laboratories, commodity purchasing data, outside data sources and more

Granta’s Material Universe14 provides ‘off-the-shelf’ technical, price, and eco property data for 3,700 types of metal, plastic, ceramic and composite – including relative cost information. This database provides an excellent initial platform for materials strategy deployments, augmented in due course with company-specific information as experience with the system develops. Overview pricing data enables the issues of cost optimization raised in Section 2.2 to be addressed, while the environmental data creates a unique tool to address the eco design issues raised in Section 2.3.

4.3 Consortium membership option

A cost-effective and ‘fast-track’ alternative to ‘going it alone’ in developing a solution is offered by the Materials Strategy Consortium15. This collaboration provides the opportunity to learn from the experience of others and to have direct input on future priorities for software development. Experience has shown that satisfaction and value from technology solutions are greatly enhanced if these solutions are not developed ‘in an ivory tower’, but, rather, in close collaboration with stakeholder organizations that have a keen interest in the outcome. This has been the strong feedback from
the analogous Materials Data Management Consortium – to the extent that the MDMC is now in its sixth year, with a membership that continues to grow.

Companies become eligible for membership of the Materials Strategy Consortium simply through a qualifying software purchase. The unique feature of the scheme is that in addition to the direct value of this software, Granta commits a matching investment to product development guided by the Consortium. The result is a larger software R&D budget and considerably more guidance from participating companies on product development direction than is available with conventional software purchases.

In summary, benefits of membership include:

- A shared cost model – members license and use the materials strategy software while also helping guide its development in line with their company’s requirements, at a fraction of the cost of ‘going it alone’
- Shared ideas, experience, expertise and funding in the solution of common problems
- Early access to new software as it is developed, ahead of non-member companies
- Training, networking and support via face-to-face meetings, conference calls, and web events with peers and Granta experts

5. Conclusion and further information

The fact is that manufacturing enterprises in today’s marketplace that do not optimize their materials strategies are likely to struggle to achieve critical strategic objectives. They may not operate as cost-effectively as they could. They may not be able to respond to regulations as efficiently as they could. Or they may make products that are less responsive to customer demands than they could be.

In this paper, we have outlined an innovative approach that ‘joins the dots’ between materials technology, strategic considerations such as cost, and an enterprise software platform. The result enables designers and purchasing/commodities personnel to have additional insight into each other’s roles, in pursuit of optimized materials specification and procurement. The approach is embodied within a proven software solution, enabling organizations to better define and implement integrated materials strategies.

For further information on the capabilities described in this paper, or to arrange a demonstration to your management colleagues, please use the contact details provided on the front cover.

References

3. Coulter, P., “The Materials Competition; Beyond price per pound in materials strategy”, presented at MS&T ’06, Cincinnati