Granta technical paper

Meeting the Materials Data Management Needs of Engineering Enterprises

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Executive summary

Materials property data, and broader materials information, are essential to a wide range of people and functions in engineering enterprises. In this paper, we focus on how this complex and specialist information must be managed, and how it can be deployed most effectively to those who need it. We concentrate on the practical challenges involved, and on the technical details of how these challenges can be solved, drawing on the experience of developing the GRANTA MI materials information management system in collaboration with a consortium of leading aerospace, energy, and defense organizations.

We explore four use-case scenarios in which the management and application of materials data are important. These are: support for engineering design, statistical process control, selection and substitution of materials, and meeting regulatory (e.g., REACH) requirements. For each use-case, we identify the technical requirements for any corporate materials data management system. We find significant overlap between the requirements for the different areas, indicating that a well-designed system can both meet a broad range of specific needs, and help to integrate different aspects of an organization’s operations.

We then discuss the actual software tools required to meet these needs. These include tools to capture and consolidate materials data, to analyze and apply the data, to maintain a corporate materials information resource, and to deploy materials data enterprise-wide to the different functions (e.g., Design, Purchasing, and Quality Assurance) and roles (e.g., design engineers, stress analysts, and process improvement managers) that require it.

We close by providing guidelines on best practice regarding implementation of materials data management technology.

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1. Introduction

1.1 Materials data – a critical resource

Materials property data, and broader materials information, are essential to a wide range of people and functions in engineering enterprises – from stress engineers and designers needing the right property data for engineering simulations, to buyers aiming for optimal purchasing decisions, to managers concerned with regulatory compliance. Materials data is also of fundamental interest, of course, to the materials engineers, quality assurance and testing personnel, and others who generate, control, and supply it.

In a previous paper we examined the business case for effective materials information management, taking a strategic perspective on issues such as productivity, innovation, and avoiding risk. We concluded that best practice could save millions of dollars and realize double-digit returns on investment. And we explored high-level requirements for such best practice.

In this paper, we approach the subject from a different perspective, examining the practical materials data management needs of those – data suppliers and data consumers – who encounter materials data day-to-day. We identify supporting features, functions, and services that they require of information technology, and we discuss how these are met by the GRANTA MI™ materials information management system. Granta Design is the leading provider of materials information technology, and the technical perspective that we outline here is informed by years of experience working with materials specialists, engineers, and their managers. In particular, we draw from work with the Material Data Management Consortium (MDMC), a collaboration of materials-focused aerospace, defense, and energy organizations, and from discussion at a series of open seminars involving representatives of dozens of leading manufacturing organizations.

1.2 The materials data management needs of engineering enterprises

At the seminars, participants from top manufacturers and materials producers were presented with a list of practical materials information needs. They were invited to identify the issues that they experienced regularly, expanding the list if necessary. There was a remarkable degree of consensus within each meeting and between the events. Table 1 itemizes some of these concerns. Such problems were common to many industries and functions.

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<table>
<thead>
<tr>
<th>Table 1. Common materials data needs.</th>
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<tbody>
<tr>
<td>1. Finding relevant materials property data</td>
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<td>2. Consolidating materials (test) data</td>
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<td>3. Gathering and continually analyzing data to monitor materials in production</td>
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<td>5. Deploying corporate materials data to engineers</td>
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<td>6. Getting correct data into finite element analyses (FEA), computer-aided design (CAD) etc…</td>
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<td>11. (For materials producers) – positioning materials relative to the competition</td>
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Tackling these problems requires that engineering enterprises and their staff can:

- **Get the right materials data** – consolidate external reference data on materials properties and processing and internal materials data (from testing and elsewhere) in one place. Enable efficient enterprise-wide access.

- **Manage materials data** – capture new data efficiently; analyze data to create useful information; maintain information resources as the base materials, data, requirements, and systems change over time.

- **Deploy materials information** – integrate materials information into the workflows of the people who need it. For example, through CAD, FEA, and other product lifecycle management (PLM) tools.

- **Use materials information** – apply this information with the right tools, to make decisions in design and in the specification and use of materials.

This paper focuses primarily on the second and third of these requirements – how can dynamic and complex materials data be managed, and deployed effectively to everyone who needs it? To answer these questions we study four specific use-cases, some or all of which will be found within every engineering enterprise.
2. Use-cases

In this section we introduce typical use-case scenarios for materials data and identify resulting requirements for materials data management.

2.1 Support for engineering design

In today’s virtual product development environment, design and simulation engineers perform detailed modeling of the performance and service life of components and assembled products. They need to load materials models into CAE programs, assured that data is accurate, approved for use, and consistent with that used elsewhere in their project and organization. They are often frustrated in this desire. Materials data on precisely the right material in the right format for the CAE program can be hard to find, requiring users to access unfamiliar systems, or collation of data from multiple sources. Often, against time pressure, it is tempting to use the easiest source, or re-use data that worked before. This may meet immediate requirements, enabling the simulation to run, and generating apparently reasonable results. However, it compromises the validity of the simulation and the ‘auditability’ of the design. It also means that the organization is not taking full advantage of investments in testing and generating approved design data.

At the root of these difficulties is the relatively complex process whereby design data (particularly the ‘allowable’ values used in aerospace engineering) are generated from test data and other inputs. Figure 1 provides a materials engineer’s perspective of this process. It begins with the capture of raw data either directly from test machines (which can generate dozens of different file formats) or from documentation, analytical models, spreadsheets, and databases. Test results are analyzed to extract key quantities (e.g., Young’s modulus or yield strength) and series of results rolled up (or ‘reduced’) to derive the allowable values. These are statistically-qualified to take account of variability and incorporate appropriate ‘safety margins’. Allowable values are frequently presented as graphs or mathematical functions, showing the variation of the property in question with strain, time, temperature, or other variables.

This process can involve results from thousands of tests and require data types ranging from simple numeric ‘single-point’ data, through Boolean data, to text and media files, and on to complicated multi-parameter models such as those describing creep or fatigue. Each step must be fully traceable. It must be possible to find not only all raw data relating to a test, but details of experimental procedures used to generate it, and of equipment, methods and parameters used to reduce and analyze it. Such
‘traceability’ has these objectives:

- To ensure design decisions have a ‘pedigree’ open to rapid and complete audit. This is critical for quality-conscious and regulated industries like aerospace or medical devices.
- To make it much easier to re-assess or update design information as new test data arrives, or as new models evolve for analyzing the data.
- To create a resource that can be re-used as requirements change or technology advances. For example, future non-linear simulations may need parameters not captured by today’s reduced test results, but which can be generated by revisiting raw data.

This, then, is the challenge for systems providing materials data to design. To the data consumer – the engineer or stress analyst – the systems must present data in an intuitive and accessible manner, ideally within existing CAD or CAE software. In the background, meanwhile, the systems must handle large quantities of specialist materials data, provide tools to analyze and approve that data, and guarantee traceability. Central to traceability is capturing complex relationships between items of data, and preserving these as data is updated.

Table 2. Technical requirements for supporting engineering design

- Capture data directly from test machines
- Handle the complete range of materials data types – numeric, discrete, Boolean, functional, graphical, multi-dimensional, etc…
- Easy (bulk) import/export of data from spreadsheets and reference/legacy databases
- Integrated data reduction tools
- Data analysis tools to generate statistically-based design ‘allowable’ values
- Access control and security, enabling materials authorities or other specialists to define who can see and use which data
- Retain all raw data, experimental details, and analysis methods/parameters – and all relationships between them (including saving original test machine data files)
- Change-management tools such as version control, to ensure the latest version of information is published while retaining history for traceability purposes
- Integration to engineer’s workflow – e.g., enable approved data to be found and used directly within FEA or other CAE software

2.2 Statistical process control (SPC)

Materials data continues to have an important role when manufacturing organizations move beyond the design phase and into production and use of their products. For example, aerospace manufacturers cannot simply assume that the actual properties of production materials consistently match the specification used in design. They must continually test production samples to certify that this is the case. Since no two samples produce an identical result for a property such as tensile strength, quality control processes must allow for, and monitor, variation. Statistical process control (SPC) typically aims to ensure not just that the property remains above a specified minimum, but that its variation remains as expected.

A simple example is the WECO rules, defined by the Western Electric Company in the 1950s and still widely used in industries such as aerospace. These rules pass or fail production runs by analyzing groups of consecutive tests. They raise an alert not only if a single result falls outside defined tolerances, but also if certain patterns occur in groups of results relative to the expected mean value or standard deviations of the property.

Such control processes require systematic capture and analysis of materials test data. A materials data management system that fulfils this function is a minimum requirement. Even better if it retains the pedigree information relating to each test, making it simple to check the certification of any batch of material. But best practice approaches to SPC go further and consider how the organization’s entire history of quality control data can be captured and continually monitored in a coherent manner.

The basic approach to SPC, however, focuses only on certifying single production batches, requiring materials data capture and analysis for only a relatively small number of tests at any one time and place. Engineering organizations who have designed their data management system to fit this basic approach find, eventually, that their body of historical quality control data is fragmented and inaccessible. Test data may not even be captured electronically in any truly re-usable way. Certification, for example, data may be held only as signed hard copy documents or scans of these documents.

One manufacturer recently experienced a problem typical of such situations. A change in a supplier’s process resulted in a material that demonstrated a significant decrease in the variability of a key property compared to the material specification, but a lower mean value for that property – as illustrated schematically in figure 2. The new material’s range...
of performance (the dotted curve) lay within the acceptable range specified for the original material (the solid curve). It continued to pass WECO-style tests on small sets of test samples designed to certify specific material batches. But testing did not initially pick up the overall decrease in the material’s performance relative to the specification.

**Figure 2. An example of failure in process control.**

A best practice SPC process that continually monitored the entire population of test results and automatically produced graphs such as those above could have aided early recognition of the changed performance. Such improved processes usually require upgraded data management capabilities, since they demand storage and on-going analysis of a coherent and complete body of test data.

In addition to the enhanced measurement of performance against design allowables, best practice can play a role in optimizing those values. We saw in section 2.1 how traceable materials data supports continuous improvement in design. Data from quality control, which today is often unused beyond its immediate purpose of certification, can help too, as Rolls-Royce Aerospace have recognized (below).

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“In engineering design we don't use average material property values but ‘allowable’ values that account for variability. If we can demonstrate that we have reduced this variation then we can improve the design allowable. To embed such optimization in our design process, all relevant materials information must be accessible from a single source and open to continuous assessment and analysis.”

Dr. Malcolm Thomas,
Director of Materials and Mechanical Behavior,
Rolls-Royce®
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This approach is visualized in figure 3, which illustrates how a design allowable is determined. The solid curve represents a series of test results with an average materials property, \( p \). The so-called ‘A Basis’ value\(^a\) used by aerospace design engineers, \( p_1 \), accounts for variability in the property. If, through analyzing product performance and test data, a materials team proves that the actual variability of the property is the dotted curve, then they can publish a new allowable, \( p_2 \). Designing with this value may enable cost or performance improvements as, due to the better knowledge of the material’s behavior, the ‘factor of safety’ can be less conservative. Yet, in many companies, such apparently simple optimization cannot happen because complete data is not available.

**Table 3. Technical requirements for supporting statistical process control.**

<table>
<thead>
<tr>
<th>Requirement</th>
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<tbody>
<tr>
<td>Capture all materials testing data from quality control processes in a single, central system</td>
</tr>
<tr>
<td>Easy (bulk) data import from test machines</td>
</tr>
<tr>
<td>Integrated data reduction tools</td>
</tr>
<tr>
<td>Specialist statistical analysis tools</td>
</tr>
<tr>
<td>Capture and maintain relationships between different data sets, making it easy to identify and analyze populations of related data</td>
</tr>
<tr>
<td>Automate analysis to enable continuous monitoring and process improvement – e.g., with e-mails notifying staff of process status</td>
</tr>
<tr>
<td>Change management – e.g., publish new materials specifications to all relevant users as soon as they are available</td>
</tr>
</tbody>
</table>

\(^a\) The A Basis allowable is defined as the value at which there is 99% confidence that 95% of the materials tested will exceed it.
2.3 Selecting and substituting materials

Perhaps the most fundamental materials task in an engineering organization is selection – choosing the best material for an application, or substituting existing materials to improve performance or reduce cost. Strategies to ensure consistent, optimized selection enterprise-wide can realize substantial savings and/or enhance products and processes. We discuss such approaches, and supporting tools, in a separate paper. In the present study, we focus on the fundamental data management and deployment requirements to ensure that designers and engineers have the information needed for optimal choices.

First, they need access to existing corporate materials knowledge. It can save hours, or even days, of work if a designer can quickly establish what has been used before. It may save even more time and effort to be able to quickly identify materials that have already been tried and rejected. This suggests the need for single corporate materials information resource containing historical materials information from testing, design, production, and product use. This resource must be quick to browse and search, ‘Google-style’, for relevant terms or attributes – a material name, a trade name, an application or device in which the material was used, or the name of a group or individual. A web-based resource in which related items are hyperlinked further increases the likelihood of being able to find relevant knowledge.

Prior corporate knowledge may be insufficient. Or it may need expanding or validating. In these cases, we have a material selection problem to solve. This may be simple and highly constrained – ‘find the cheapest polypropylene grade from our preferred materials list that meets criteria for strength and sterilizability’, or ‘what other alloy has these properties but contains less chromium?’ Less frequently, there may be an entirely open problem – ‘what material would work best?’ Problems are often tackled pragmatically, drawing on the designer’s knowledge, supported by materials reference data. Systematic approaches are still surprisingly rare. These use a clearly-defined method and supporting tools and are likely to follow a pattern described by Ashby. Indeed, even pragmatic selections are likely to involve a similar thought-process, although the steps may be less explicit. Broadly, this process is:

- **Translate** design requirements into a required function and overall objective (e.g., ‘minimize cost’), noting constraints and ‘free’ variables
- **Screen** the set of candidate materials (in rare cases, all known materials) using the constraints. Eliminate those that cannot satisfy them.
- **Rank** remaining materials using the overall objective(s)
- **Study** top-ranked materials in detail by consulting reference sources. Evaluate trade-offs between objectives before making the choice.

However the process is conducted, it has the following basic information requirements:

- A combination of technical, economic, and environmental property data. Designers want to minimize the number of sources required to assemble such data – ideally, to a single source.
- Quantitative data stored in a structured fashion enabling easy comparison. Ideally, analysis tools are integrated into the data management system or connected by simple import / export.
- **Materials reference data** from external sources (handbooks, databases, data services…) to aid screening and ranking. This must be comparable (e.g., attributes are measured consistently for every material) and complete (to avoid excluding materials simply because one property value is missing).
- Data that is approved, up-to-date, and consistent across the enterprise.
- Access to as much information as possible in support of the final detailed study stage. This reinforces the need for a single, searchable source of corporate materials knowledge.

Table 4. Technical requirements for supporting materials selection

<table>
<thead>
<tr>
<th>Requirement Description</th>
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<tbody>
<tr>
<td>A single, central materials database in which all corporate materials information is captured</td>
</tr>
<tr>
<td>Simple browser-based access to this resource, with web-style search and browse capabilities</td>
</tr>
<tr>
<td>A database containing both unstructured text and structured data, and that captures and preserves relationships between items</td>
</tr>
<tr>
<td>Integration with, or simple export of data to, selection and analysis tools</td>
</tr>
<tr>
<td>Integration of external and internal data – technical, price, and environmental data</td>
</tr>
<tr>
<td>Reference sources offering comparable data with few or no ‘holes’ in the data</td>
</tr>
<tr>
<td>Access control, security, and version control capabilities to ensure users have the latest data that is both approved and authorized</td>
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2.4 Regulatory requirements (e.g., REACH)

Consumer and societal pressure and corporate social responsibility mean that an ever widening range of environmental, health, and safety factors need to be considered in design and production. An example from the resulting global wave of legislation is the European Union’s REACH\textsuperscript{11} directive on restricted substances, which impacts any manufacturer or materials provider trading in Europe.

The materials information challenge set by REACH sounds simple. Manufacturers need to know what materials are in their products and processes. They need to be able to report on compliance with REACH and to substitute materials if necessary to ensure compliance. In practice, this is a tough problem, particularly for organizations making hundreds of products, or whose products contain sub-systems and thousands of components. Information on materials in current products may be available through the Bill of Materials (BoM) capability in their Product Data Management (PDM) or Enterprise Resource Planning (ERP) system. However, for less recent products, it is likely to be scattered across a variety of databases and file systems. For older products still, it may be available only in hard copy.

Once this information is found, it needs to be compared against relevant lists of restricted (or, alternatively, authorized) materials. These lists are themselves dynamic. The resulting combined query can be surprisingly complex – e.g., requiring information on alternative grades of a material, on equivalent materials, or on the maximum permissible percentage of a material allowed in an alloy. Finally, this information needs to be used to take decisions – e.g., how to replace the material or reduce the amount used. This requires detailed data, from proprietary or external reference sources, as described in section 2.3.

Table 5. Technical requirements to address restricted substances legislation

- A central database, holding all the attributes of the company’s materials and processes
- Integration to the system (typically PDM or ERP) holding the Bills of Materials (BoM)
- Integration to a reference database of restricted substances legislation, and the associated restricted materials list(s)
- Tools to compare materials and to inform materials selection and substitution
- Facilities to repeat analyses and propagate change notifications following updates to the databases

3. Available tools

The use-cases outlined in section 2 generate a list of requirements for materials data and its management (summarized in tables 2, 3, 4, and 5). It is noticeable that many of these requirements overlap, so that a well-designed materials information management system could provide benefits in many parts of an engineering organization. In this section, we describe the necessary components for such a system, drawing on the experience of developing the GRANTA MI system in association with the Material Data Management Consortium and others.

3.1 Capturing and consolidating data

A consistent primary requirement in our scenarios was a single, central source of materials information, in which all relevant data is captured and consolidated. We need somewhere to put this information – a database developed and optimized specifically for materials data. This must have certain capabilities, all of which were part of the core design brief for GRANTA MI:

- **Materials domain support.** The database needs to handle the specifics of materials information – properties, units, conventions, etc. Ideally, such domain support should be built-in, so that materials experts can configure the system without extensive customization.

- **Support of all relevant data types.** The database must support not just numbers and graphs, but also unstructured text, mathematical functions, images, documents, Booleans, and discrete data.

- **Relational structure.** The database must be able to capture and preserve the vital
relationships between different data sets and, with them, their ‘pedigree’ or metadata.

- **Flexibility.** It needs to be easy to create and update a specific data structure for each organization – known as the *schema* – that defines and organizes the relevant types of data, their attributes, and the connections between them.

Balancing these requirements necessitates software design based on a combination of materials domain knowledge and information technology expertise. For example, if there is insufficient schema flexibility, ‘hard-wiring’ the database for the needs of materials technologists can conflict with the flexibility required to meet the needs of different groups of end-users for the data. Such difficulties can sink in-house materials information projects.

A successful schema for a GRANTA MI database to store laboratory test data is provided in figure 6. This has evolved over a number of years’ work with the Material Data Management Consortium. It is used as a template by members and refined for their own test data management needs.

Given the right database software and database schema, the next requirement is to get data into the system. The GRANTA MI system can integrate data from the following sources:

- A wide range of external references (e.g., MMPDS aerospace materials, CAMPUS plastics, MaterialUniverse generic materials property data) are available off-the-shelf as GRANTA MI databases, providing technical, economic, and environmental property data.

- Data can be imported directly from the output files of materials testing machines – e.g., from Instron or MTS tensile test machines.

- Data can be imported from ASCII text files, and users can easily create their own importers, allowing integration of data from any equipment producing ASCII output.

- Data can be imported from Microsoft Excel files and worksheets.

- Documents (e.g., images, Word files, PDF documents, video) can be imported to the database as ‘embedded media’ files.

To fit in an organization’s existing materials information landscape, a number of further capabilities are required for the practical implementation of data capture and integration tools. These include:

- Batch import of large quantities of data.

- Automation of such import, including placement of data in the database according to user-defined rules, and automated creation of links between related items.

- Conversion of numerical data into units of the user’s choice on import, helping to ensure consistency and comparability.

- Capture of raw data files (as well as imported data values extracted from these files) to ensure full traceability back to the original instance of a piece of information.
Such capabilities meet the requirements for creating a single, central, corporate materials information resource. GRANTA MI then allows data to be browsed, searched, and viewed via a simple web browser interface. This may meet all of the organization’s materials information management needs if, as is sometimes the case, these extend no further than to consolidate legacy proprietary data and/or useful external references, and to enable efficient ‘look up’ of that data. Most organizations, however, see their corporate materials database as a more dynamic resource – they want to continually add data, to analyze that data to generate new or updated information, and to apply that information.

### 3.2 Analyzing and applying materials data

We can separate materials analysis tools into two sets. First, there are tools applied by materials experts to: process and analyze raw materials data in order to create approved design data for wider publication; to update and refine this information; and to apply this data and information in specialist applications such as statistical process control. We shall call these **materials data management tools**.

Second, there are tools used by the wider community of engineers, designers, and decision-makers to apply materials information in design, selection, and other business applications. Some of these simply use materials data as input. We shall discuss integration with these in section 3.4. Other tools perform analyses on materials data in order to facilitate decision-making. We shall call these **materials strategy tools**.

**Materials data management tools** – a comprehensive suite of these has been developed by the Material Data Management Consortium for test data. These tools, summarized in table 6, enable roll-up and analysis of raw results from a range of different test types, and generation of statistically-backed design data. Important aspects of these tools are:

- They offer the range of analyses required by materials scientists and technologists – from single test results, to multiple points, to multiple curves.
- They are fully integrated with the GRANTA MI database and easy-to-use – analyses are completed using a Windows user interface or within an Excel spreadsheet (see figure 7), and results are saved directly into the database.
- Results can be permanently linked to raw data input and analysis details in the database for full traceability.

<table>
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<th>Test Modules</th>
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<tr>
<td>Tensile</td>
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<td>Compression</td>
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<td>Creep</td>
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<tr>
<td>Stress relaxation</td>
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<td>LCF / cyclic deformation</td>
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<td>Fatigue crack growth</td>
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<td>E399 fracture toughness</td>
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<td>E561 fracture toughness</td>
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<td>E1820 fracture toughness</td>
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<th>Quasi-Static:</th>
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<td>Stress v strain curves (for stress and strain controlled tests): Ramberg-Osgood Model</td>
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<th>Creep models:</th>
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<tr>
<td>To fit test load as a function of time to failure and other % creep strains at various constant temperatures): Larson Miller model (for creep and creep rupture)</td>
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<td>Hyperbolic tangent modent (for creep rupture, MDMC only)</td>
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<th>Fatigue:</th>
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<tr>
<td>Stress v life curves (for stress controlled tests):</td>
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<td>o Basquin model</td>
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<td>o Life power model</td>
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<td>o Equivalent stress (as in MMPDS)</td>
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<tr>
<td>o Ramberg-Osgood model</td>
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<tr>
<td>Strain v life curve (for strain controlled tests):</td>
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<tr>
<td>o Coffin-Manson</td>
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<tr>
<td>o Combined Basquin and Coffin-Manson</td>
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<td>o Life power model</td>
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<tr>
<td>o Equivalent strain (as in MMPDS)</td>
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Functionality to meet the needs of the statistical process control case (section 2.2) represents another example of materials data management tool. An SPC integration continually accesses test data from the production process, automatically determining relevant properties from each test, and adding these to the history of such results stored elsewhere in the database. This population is itself continually analyzed, generating plots that make clear any deviations from the expected or required behavior.

**Materials strategy tools** - the detailed methodology of such tools (for example, for materials selection for optimum cost, or eco auditing) is beyond the scope of this paper. What is relevant here is how such tools are integrated into a
materials data management architecture. Again, GRANTA MI provides examples.

The Enterprise Materials Optimizer (EMO)\textsuperscript{15} is a web-based tool that enables designers to rank materials in the GRANTA MI database according to design objectives such as ‘lowest cost for a beam in bending’. Users specify their design objectives using a series of intuitive drop-down menus and input boxes. These can be applied to any chosen set of materials from the corporate database, with the system finding and applying the relevant technical, price, and other data. Results are returned as a ranked list, with links to datasheets providing detail on each material. The calculation can be automatically focused on the company’s ‘preferred materials’ – a classification that is kept up-to-date in the central database – allowing designers to take account of business strategy in making choices.

The user of any of these selection tools needs to be assured of the pedigree and currency of the data that they draw on. How, then, can a complex materials information resource be maintained in a situation where both the data and the user requirements may constantly change?

3.3 Maintaining a corporate materials data resource

Among the features of GRANTA MI designed for this maintenance challenge are:

- **Version control** – the database stores the history of any record, dataset, or item of data, including explanations of changes made. It enables control of the process by which updates are published – for example, this may require specific approvals. This assures the user that they are seeing the most recent approved data, and also allows changes to be traced and analyzed.

- **Traceability and pedigree** – any item of data can be permanently linked to any other item in the database. This link is preserved, for example, even when items of data are moved or amended.

- **‘Smart’ links** – these automate creation and maintenance of links. For example, they allow an operator to ensure that results from a particular type of analysis are always linked to the input data. Conversely, by defining that certain types of data must always be linked in a certain way, smart links prevent users from amending data in a manner that would violate these rules. Enforcing such ‘rules’ ensures that a company’s data stays organized.

- **Schema updates and development** – we saw the importance of the database schema in section 3.1. Changing requirements or knowledge may mean that the schema needs refined. Tools are provided to enable changes without losing data or relationships.

- **Access control** – it is important to ensure that data is seen only by those authorized to see it. The reasons may be competitive, legal, regulatory, and even, in some applications, national security. Usability is also a factor – many applications are easier if the user is only exposed to relevant data. Access control implements this requirement.

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Figure 7. GRANTA MI analysis for creep rupture. In this case analysis is performed using a GRANTA MI plug-in within Microsoft Excel, which interfaces directly with the database to get data and store results.
Updated reference content – some of the data in a GRANTA MI implementation may be external reference information. This is updated periodically, for example, annually. GRANTA MI is also used to access on-line resources that are updated more regularly.

3.4 Deploying information

We have seen how materials data can be captured, accessed and used, and then maintained. But how does the implementing organization ensure that materials information is fully leveraged across the enterprise – including by those who may not wish to go looking for it? Or even by those who may not be aware that they need it?

A good example is the engineering design use-case scenario discussed in Section 2.1. Simulation engineers require materials data as an input to their simulations. Their interest is in acquiring the right data quickly and reliably, to run their simulation jobs promptly and get valid results. They don’t need or want to understand and navigate the underlying test data and data derivation procedures – they just need to know they can trust the result.

We have already discussed two mechanisms for distributing materials data – tailored analysis applications, more suited to the expert user, and via web browsers. GRANTA MI allows anyone with appropriate authorization to search and browse its database via a browser, and to export data in file formats that can be read by many common computer-aided engineering applications.

A higher level of integration can be achieved through ‘plug-ins’. These sit within a third-party application – e.g., a finite element analysis package – and allow materials data to be accessed directly from within that application. For example, the plug-in to the Abaqus CAE system shown in figure 8 enables Abaqus users to browse and search in-house or reference materials databases, to pick from a Favorites list, to choose the applicable materials model and units system, and to apply the data directly to their model, all without ever leaving the CAE environment. They may not even know, or need to know, that they are interacting with GRANTA MI.

This is an example of an off-the-shelf plug-in provided by Granta, and created using GRANTA MI’s Application Programming Interface (API). Such API’s – increasingly, today, following the web services paradigm – represent the means by which a materials information management system integrates with other enterprise systems in the engineering PLM infrastructure.

The wider availability enabled by this integration considerably extends the scope of the materials system – and enables its information to have impact not only in ‘conventional’ materials selection in design, but also in purchasing and regulatory compliance. This is the means, for example, of enabling Bill of Materials integration to address the requirements of the REACH use-case scenario discussed in section 2.4.

Typically, APIs are available for use both by organizations’ internal programmers, and by the software providers themselves when providing complete solutions to their customers.
4. Practical considerations

In this section, we outline some practical issues to consider in implementing a materials data management system. Again, we use GRANTA MI as an example.

4.1 Scope, scalability, and flexibility

The more functions and applications across which materials data management is implemented, the more the organization will benefit – both through economies of scale (since much of the data and many system components are common) and through improved sharing of knowledge enterprise-wide.

However, it is often the case that organizations want to implement materials data management in support of a specific function or project – perhaps where the need is most urgent or apparent, or as a ‘pilot’ for wider application. Thus, flexibility is important. Implementations must be cost-effective, efficient, and usable as small ‘groupware’ implementations supporting, perhaps, a few tens of materials experts and engineers – while scaling effectively to support the thousands of engineers who may need to access materials data across a large engineering enterprise.

This requires the solution designer to give thought to the following issues, all of which are addressed in GRANTA MI:

- **Modularity** – performance, cost, and convenience are all optimized if the organization has to install only those parts of the system that it needs. GRANTA MI is a modular system (see figure 9) with core and optional components, depending on the requirements of the implementing organization.

- **Usability** – practical implementation of a system across an enterprise demands careful consideration in designing the system for all stakeholders. Different technologies, user interface and workflow approaches, and terminology may be needed to support different users. For example, GRANTA MI allows data access for occasional users via a web browser in the context of comprehensive instructions in non-technical language. A materials expert, meanwhile, might interact intensively with the same data via an Excel-based analysis application with detailed functionality described in the language of materials technology.

- **Speed** – the database technology must be robust and ensure quick response to requests, even as its use scales up to large user-bases and/or large datasets. GRANTA MI is built on standard database technology that is widely used to support both small groupware and enterprise-wide implementations.

- **Cost and licensing** – these need to minimize administrative burden and ensure cost-effectiveness as use spreads.

- **Implementation costs** – the challenge here is to balance flexibility against the extent of up-front ‘customization’. We discuss this further in Section 4.3.

Figure 9. GRANTA MI is a modular system.

<table>
<thead>
<tr>
<th>GRANTA MI modules &amp; related tools</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mi:Server</strong> – core database and related data management tools</td>
</tr>
<tr>
<td><strong>Mi:Viewer</strong> – browser-based access to information and tools</td>
</tr>
<tr>
<td><strong>Mi:Admin</strong> – enables configuration &amp; control of the system</td>
</tr>
<tr>
<td><strong>Mi:API</strong> – enables plug-ins</td>
</tr>
<tr>
<td><strong>Mi:Toolbox</strong> – Windows data processing tools</td>
</tr>
<tr>
<td><strong>Mi:Lab Analysis</strong> – test data analysis (Excel-based)</td>
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<tr>
<td><strong>Mi:EMO</strong> – materials decision support</td>
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<tr>
<td><strong>CES Selector</strong> – complementary materials selection software</td>
</tr>
<tr>
<td><strong>Reference data</strong> – supporting materials property &amp; process data</td>
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</tbody>
</table>
4.2 In-house versus ‘COTS’ software

Of course, GRANTA MI is just one route to meet the materials data management needs of a project or organization. Of the other options, perhaps the most tempting and widely-considered is to ‘go it alone’ and build a system in-house using the organization’s own IT staff or contractors. After all, the organization knows its own data the best, and surely (the argument goes…) the required system components are relatively standard database, statistical analysis, or data visualization tools?

Depending on the scope of the project, in-house solutions can work well. But, long-term, they are invariably more expensive than a ‘commercial off-the-shelf’ (COTS) solution. This is not always immediately apparent, as costs may be hidden in salaries or other indirect staff or contractor costs. The experience of the Material Data Management Consortium is a good example. Members not only use GRANTA MI, but provide guidance to its ongoing development. This has ensured creation of, for example, specific test data importers and analysis modules. The development cost is shared between the sixteen members and other Granta customers, rather than borne by one organization.

While it may be true in some respects that ‘a standard database should be able to do the job’, such an approach first requires creation of a materials data management application ‘layer’ above that standard database, to support the functions outlined in this paper. That layer is embodied in GRANTA MI, and the size of the task of creating and maintaining it is frequently underestimated in in-house developments.

We met another issue when discussing database schema design in section 3.1, in which we noted that it could be hard to balance domain support against flexibility. Some companies have had to make several iterations in the design of their in-house systems, and the luxury of several chances is rare in any IT development project! Experience of combining materials knowledge with building and deploying successful software is very valuable – and in-house projects can be risky in the absence of such specific experience.

Finally, perhaps the biggest single factor to consider in evaluating the in-house option is maintenance. Cost justifications for in-house IT projects typically underestimate the maintenance costs of a system over its lifetime. What happens when new features are required? Or specifications change? Or operating systems or hardware updated? Or merger, acquisition, or strategy changes need demand integration of the system with someone else’s? Has the knowledge needed to do this been retained? Have standard, rather than proprietary technologies been used? Is the system architecture sufficiently open and flexible? If so, what did all of this cost? A significant percentage of the initial IT project to develop an in-house system (including the application layer defined above) needs to be set aside every year to keep a system useful.

In-house may be the right option. But it is one that requires very careful consideration. It is worth repeating again that the 16 companies in the MDMC, the largest commercial collaborative project in materials data management ever undertaken, each elected to take the ‘COTS’ route.

4.3 Implementation

Of course, ‘off-the-shelf’ doesn’t mean ‘straight out of the box’. It would be misleading to suggest that any serious materials data management system can be installed and work instantly, for reasons that are inherent in the requirements discussed above. The sort of flexibility we have suggested necessitates the installation of different components, in different places, for different people. To integrate to existing business systems or CAE software, connections will need to be built. To consolidate all materials data in one place will usually require some data capture, processing, and organization – and possibly some modification of a database schema.

Conversely, we have noted that many of the elements of a materials data management system are common, whatever the use-case – and these are what have been designed into GRANTA MI. There should rarely be the need for software customization – instead deployment consists simply of configuring the COTS software to operate with requirements, engineering practice, data flow and terminology. Typical steps include:

- Defining the main function of the system
- Considering how the system fits with existing systems and workplace practices – applying (or creating) plug-in or file importer/exporter utilities, as necessary
- Determining the users and stakeholders for whom the system needs to be successful – the materials data producers, and the various different end-users/consumers of the data
- Considering how each of these user groups will use the system – installing the necessary components in the right place and providing training, if needed
• Analyzing how data flows through the system, what type of information will be handled, and how the system will be set up, deployed and maintained – e.g., to ensure that initial ‘launch’ data is imported, subsequent maintenance and update procedures are in place, and access control settings are applied

• Deciding who is responsible for, and owns, the various system components – to ensure ongoing support and maintenance

5. Conclusions

Effective management and use of materials data and information impacts business-critical applications. For any and all of the applications, detailed technical requirements must be carefully considered in order to achieve best practice. There is little point, for example, in implementing comprehensive data capture tools if the resulting data is never analyzed or used.

Analysis of, and experience with, a number of common use-cases has allowed us to identify many of these requirements. We have described them, and one route to meeting them, in this paper – to help anyone considering whether and how to improve their materials data management.

There is now significant experience of applying such technology, through projects such as the MDMC, and through use in individual engineering organizations. We will continue to learn lessons from this experience that will further improve the tools and their future application. To that end, we are always interested in hearing about your experience of materials data management.

E-mail info@grantadesign.com.

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