Granta technical paper

Data Management for Composite Materials

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Executive summary

Composite materials have a growing importance, particularly in high-performance engineering sectors such as aerospace. Anyone selecting these materials, designing products that use them, or even marketing them, needs good data on their properties and processing, and good tools to apply this data.

Reference data about composites is now available from sources including CMH-17, AGATE, NCAMP, and IDES, although this data can be difficult to collate, access, and use. But reference data alone is rarely enough. Companies need to determine and validate properties themselves, often performing extensive testing. This is particularly true of composites, because of the dependence of their properties on factors, such as geometry and process history, that vary with each application.

Generating this test data represents a major cost for many organizations. And applying it effectively can give them a major competitive advantage – for example, avoiding problems in product design and gaining more performance from their materials. Yet few organizations have in place any systematic system to manage this valuable asset. Not only does this mean that they are not making best use of their investment in composite data, it means that they actually waste large amounts of time and money, for example, in searching for the right data, or in duplicating tests that have already been done.

So why is systematic composite data management not yet widely implemented? The main reason is because it has posed some difficult technical challenges. The data involved are specialist and the nature of composite systems means that a complex web of inter-related data is usually required to describe them. These challenges are magnified if we pursue the goal that all composite data is ‘traceable’ – an important objective in best practice data management that allows, for example, any piece of design data to be quickly traced back to the raw test data and analyses from which it was derived.

The good news is that these problems can now be addressed. Data management systems for conventional materials are now widely used. The leading such system, GRANTA MI, was developed in collaboration with the Material Data Management Consortium (MDMC), a project involving leading aerospace, defense, and energy enterprises such as Boeing, Rolls-Royce, and NASA. The MDMC has now turned its attention to developing tools that overcome the particular problems of composite data management.

In this paper, we examine the special challenges of managing composite data. We discuss the merits of different approaches to developing composite data management systems, identifying the advantages of a using commercial-off-the-shelf (COTS) software. We itemize requirements for such a system, and show how the GRANTA MI software system meets these requirements, in particular through its flexible composite database schema and ability to capture the vital links between related items of composite data.

The result is a system, now in use at leading engineering enterprises, that enables best practice in composite data management, delivering efficient access to key composite reference data, improving productivity in the use of test data, helping to optimize product design, and reducing risk due to the use of incorrect or obsolete data.
1. Introducing composite data

1.1 The importance of materials and process data for users and producers of composites

The growing importance of composite materials is illustrated by a statistic from the commercial aerospace industry. The first serious composite applications were on Boeing and Airbus aircraft in the 1980s. About 6% of the structure’s weight was composites. Boeing’s new 787 Dreamliner has 50% composite content.¹

Composites are a key focus for materials innovation and application – for example, in high-performance engineering applications that require strong, light materials, or where there is a need to tailor the properties of the material to the stress field experienced in the application. In addition to aerospace, big users of composites include: marine engineering, sports equipment, defense, and wind turbines.

A common reason for the use of composites is that they deliver outstanding mechanical properties at lower weight when compared to conventional materials – for example, to the aluminum alloys used in aerospace. This is illustrated in Figure 1. Such property comparisons are essential when selecting materials – or, conversely, when marketing materials for particular applications. These comparisons require the right property data – not just about technical properties, but about economic and environmental properties, and process history. There is also a need for tools to analyze this data and present the results – for example, the CES Selector™ software² used to create Figure 1.

Materials selection is just one activity for which materials and process data (and the associated tools) are important. Perhaps the most important application is in detailed product design – for example, during computer-aided design (CAD) and computer-aided engineering (CAE). The effectiveness of these activities is very dependent on the accuracy and fitness-for-purpose of the materials data that underlies them. And ineffective design and modeling can be very costly, leading to delays further down the product development cycle, or even problems with the final product.

Once a product has been produced, materials data remains very important. Through quality assurance and testing activities, manufacturing organizations seek to ensure that the performance of the material in use is as expected, and to refine their knowledge of the material. They also continually refine product designs, and will often need to change materials or the way in which they

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¹ The effectiveness of design activities is very dependent on the accuracy and fitness-for-purpose of underlying materials data.

² Materials selection is just one activity for which materials and process data (and the associated tools) are important. Perhaps the most important application is in detailed product design – for example, during computer-aided design (CAD) and computer-aided engineering (CAE). The effectiveness of these activities is very dependent on the accuracy and fitness-for-purpose of the materials data that underlies them. And ineffective design and modeling can be very costly, leading to delays further down the product development cycle, or even problems with the final product.

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**Figure 1.** Comparing materials properties – composites provide high strength at low density (materials property chart created using Granta’s CES Selector software)
are used (e.g., to substitute obsolete materials, to improve performance, or to optimize cost). Similarly, composite producers seek to innovate and continually improve the materials themselves. All of these activities require the right composite data – data that is often complex and in large quantities.

1.2 Data sources – reference data and ‘in-house’ testing

So where do users and producers of composites get this data? Sources of fundamental reference data about composites and their properties, although patchy, are increasing in number and quality. They include the AGATE project, the Composite Materials Handbook CMH-17 (formerly Mil-Handbook-17), NCAMP, IDES, and Granta’s MaterialUniverse data module. One challenge that engineers face in using such data is finding it in an easily-accessible, digital format. In the worst cases, it is only available in hard copy handbooks or PDF copies of these documents. Even if available digitally, the data is often not in formats (e.g., design curves) that are easy for a materials engineer or designer to use. Or it is hard to export the data for use in CAD, CAE, or other systems.

As we shall see, today’s best practice materials information systems help to overcome such problems.

But reference data is only part of the picture – in fact, for many larger engineering organizations it is only a small part of the picture. These organizations perform extensive testing (either in-house or with outsourced service companies) to create their own data. The aim is to validate properties and generate statistically-relevant design data. Such testing is particularly important for composites, where the dependence of materials performance on factors such as component geometry and process history mean that reference data can usually be regarded as only a guide, rather than information that is usable in design. So users and producers of composites typically need to capture, process, analyze, retain, share, and use high volumes of materials data. Thus the management of materials data becomes a critical issue.

1.3 Materials data management – and why composites are different

The need for materials data management is, of course, not unique to composites. In a previous white paper, we discussed the cost of traditional approaches to managing such data for the full range of materials – metals, plastics, composites, and ceramics. Data is typically stored on paper, in assorted spreadsheets, or in generic database systems not designed for materials information. Expert tools that analyze or use materials data tend to be isolated – it is hard to get data into and out of these tools. Data sources are often scattered across the organization. We concluded that such an approach can cost millions of dollars in lost productivity, repeated tests, lower product quality, higher risk, and missed opportunities for innovation.

Solutions to these challenges are now well-established for conventional materials. An example is the work of the Material Data Management Consortium. This collaboration of leading aerospace, defense, and energy organizations (Table 1) has defined requirements for best practice materials data management. We have summarized these requirements in a technical paper, and they are met through the GRANTA MI materials information management system. This system is now mature, robust, and widely used – for example, to manage, analyze, and apply data relating to aerospace alloys.

Yet, until comparatively recently, similar progress has not been made in the case of composites. The difficulty of overcoming materials data management problems greatly increases for composites, because the information required to describe them is inherently more complex. Composites can be highly anisotropic, they consist of relatively complex combinations of materials in which matrix (e.g., polymer resin) and reinforcement (e.g., fiber) properties are both critical to performance. And, as we have seen, their properties are more dependent on geometry and processing routes than many other materials.

Such dependencies, however, also mean that the value of managing composite data is often much greater than for conventional materials. This value has driven the Composites Sub-Committee of the Material Data Management Consortium to identify the specific problems of composite data management, and to work with Granta Design to develop tools that overcome them. The rest of this paper explores these problems and their solution.
2. Composite data management challenges

2.1 Materials pedigree and properties

The challenges of composite data management begin with the most basic fact about these materials. They consist of more than one material. Those materials can have a number of different roles and relationships to one another – as matrix materials, adhesives, reinforcements, fillers, sandwich cores, and so on (Figure 2).

Such structures pose a number of problems for any systematic materials data management system, the most prominent of which is the need to store and link to ‘pedigree’ or process history information.

It is vital to keep good pedigree information. Companies may want to ensure ‘traceability’ from any testing or design data back to raw data about the original batch of material. Or they may simply want it to be possible to find all test and production data related to a specific material batch or production run. For example, in aerospace engineering, if a test shows a problem in materials production, engineers will want to quickly find full information about the source for this material, its processing, and where else it has been used. Regulators or customers may demand similar searches as a matter of routine. Without effective materials data management, these searches can take days, weeks, even months. They should take minutes.

Enabling efficient, speedy traceability requires an information system that can capture the data about every batch of material, every test, and every analysis in a single, central database, as well as automatically linking related items of data, and maintaining those links as data is manipulated or used.

This is a difficult information management problem, since the web of connections builds up rapidly as test data is processed, reduced, combined with other data, analyzed to create statistical design data, and finally applied in design.

For a monolithic material, such as a piece of metal, at least the starting point is a single entity with a single set of properties. For a composite, the ‘raw material’ may consist of matrix materials (e.g., polymers, metals, or ceramics), reinforcements (e.g., fibers, particles, or whiskers), intermediates (e.g., prepregs, pre-forms or woven and braided cloths), core systems for sandwich structures, and adhesives. In data management terms, we will need to define a structure such as the hierarchy shown in Table 2 in order to store this data.

![Figure 2. Types of composite material.](image)

Table 2. Example data hierarchy for storing composite material process data

<table>
<thead>
<tr>
<th>CONSTITUENT MATERIALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matrix materials</td>
</tr>
<tr>
<td>- Polymer matrix</td>
</tr>
<tr>
<td>- Metal matrix</td>
</tr>
<tr>
<td>- Ceramic matrix</td>
</tr>
<tr>
<td>Reinforcement materials</td>
</tr>
<tr>
<td>- Continuous</td>
</tr>
<tr>
<td>- Fibers</td>
</tr>
<tr>
<td>- Aligned</td>
</tr>
<tr>
<td>- Random</td>
</tr>
<tr>
<td>Intermediates</td>
</tr>
<tr>
<td>- Prepregs</td>
</tr>
<tr>
<td>- Weaves</td>
</tr>
<tr>
<td>- Pre-forms</td>
</tr>
<tr>
<td>Adhesives</td>
</tr>
<tr>
<td>- Pre-treatments</td>
</tr>
<tr>
<td>- Fiber sizing</td>
</tr>
</tbody>
</table>

Best practice composite data management demands that we store and can easily retrieve all of the relationships between the material and each of its constituents, and any relationships between constituents (e.g., which reinforcements can be used with which intermediates). Only by retaining all of this data could we, for example,
establish trends between the final properties of a laminate and, e.g., different fiber sizing.

Composites also require us to store additional data that is not typically required in describing conventional materials. Table 3 provides some examples, including specialist property information and additional ‘meta data’ that describes how the components are integrated in the composite.

Table 3 – Examples of materials property information that is unique to composites

<table>
<thead>
<tr>
<th>Item</th>
<th>Additional information &amp; links</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforcements</td>
<td>Physical form (fiber diameter, bundle size)</td>
</tr>
<tr>
<td></td>
<td>Surface treatments</td>
</tr>
<tr>
<td></td>
<td>Links to: associated intermediates, laminates, test records</td>
</tr>
<tr>
<td>Intermediates</td>
<td>Physical form and properties (thickness, areal weight)</td>
</tr>
<tr>
<td></td>
<td>Laminate properties (e.g., ply thickness)</td>
</tr>
<tr>
<td></td>
<td>Processing data (e.g., B-stage cure cycle parameters)</td>
</tr>
<tr>
<td></td>
<td>Links to: associated constituents and laminates, test records…</td>
</tr>
<tr>
<td>Adhesives</td>
<td>Physical form and properties – viscosity, $T_v$ …</td>
</tr>
<tr>
<td></td>
<td>Bond strengths</td>
</tr>
<tr>
<td></td>
<td>Processing data – cure cycle parameters</td>
</tr>
<tr>
<td></td>
<td>Links to – associated assemblies, test records…</td>
</tr>
</tbody>
</table>

2.2 Anisotropy and the environment

Materials property data is, by its nature, complex and specialized. The systems used to manage this data must respond to this. For example, these systems need to handle specialist units and conventions. They need to ‘build in’ the formulae, algorithms, and models that describe and analyze relationships between these properties in order to generate useful information for the materials engineer or designer. Much of this data and information is multi-dimensional. A material property is often not described by a single number, but by a series of functions or graphs that show its variability with environmental variables such as temperature and humidity. This data may itself be a statistical summary of thousands of test results.

Composites complicate matters further. They add extra dimensions to the data, since composites are invariably anisotropic, exhibiting different properties in different directions. For example, the ultimate tensile strength of a fiber-reinforced composite in which the fibers are aligned is likely to be radically different in the direction of alignment, $\sigma_{Tu11}$ or $\sigma_{Tu2}$, to the ultimate tensile strength perpendicular to this direction, $\sigma_{Tu22}$ or $\sigma_{Tu3}$.

Composites often require consideration of additional variables compared to monolithic materials, where temperature time and strain rate are usually more than sufficient to cover all the variables. Examples include humidity and reinforcement volume fraction (usually referred to as $V_f$ in PMCs), which can dramatically alter the mechanical performance of laminated composite materials, while having very little effect on competing alloys.

2.3 Geometry, processing, and ‘producability’

A component made from a piece of metal is typically manufactured by taking a piece of the material, processing it in some way (such as heat treating it), shaping it to create the final geometry, and perhaps joining it to the larger system or component of which it is a part. But with a composite, the material is constructed at the same time as the component. For example, a laminate composite may be built layer-by-layer into the desired shape and then ‘cured’ to create the final component. Even when considering “bulk” composites, such as short fiber reinforced composites (PMC, MMC and CMC), the localized properties will be influenced by the fiber distributions and directionality imparted during flow within the mold cavity.
Composites often require consideration of additional variables compared to monolithic materials. Instead, there is a need to define and test properties not for a ‘bulk’ material, but for that material in a wide range of possible geometries and volume fractions (e.g., the laminates and assemblies in Table 4).

Table 4 – Example data hierarchy for storing data on laminates and assemblies

<table>
<thead>
<tr>
<th>Laminates And Assemblies</th>
<th>Additional information &amp; links</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Laminates</strong></td>
<td></td>
</tr>
<tr>
<td>Plain</td>
<td></td>
</tr>
<tr>
<td>Multiple Vf</td>
<td></td>
</tr>
<tr>
<td>Stacking sequences</td>
<td></td>
</tr>
<tr>
<td>With holes</td>
<td></td>
</tr>
<tr>
<td>Multiple Vf</td>
<td></td>
</tr>
<tr>
<td>Stacking sequences</td>
<td></td>
</tr>
<tr>
<td>Damaged</td>
<td></td>
</tr>
<tr>
<td>Manufacturing artifacts</td>
<td></td>
</tr>
<tr>
<td>CAI</td>
<td></td>
</tr>
<tr>
<td><strong>Sandwich panels</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Assemblies</strong></td>
<td></td>
</tr>
<tr>
<td>Joints</td>
<td></td>
</tr>
<tr>
<td>Lap joints</td>
<td></td>
</tr>
<tr>
<td>T-joints</td>
<td></td>
</tr>
<tr>
<td>Stiffened panels</td>
<td></td>
</tr>
</tbody>
</table>

Similarly, since processing is not a series of discrete steps applied to the virgin material, but an integral part of making the component, it follows that the process and material property data must be very well integrated. Overall, many more permutations of material, geometry, and process are likely.

As well as making the design of data management systems harder, this means that there is likely to be a greater need to store, analyze, and present test data that can capture the performance of the different configurations. Again, some of the properties relating to processing and geometry will be unique to composites – see Table 5.

A final point is that, much more than for other material types, the question often arises whether a particular geometry can be produced at all using a particular composite material. Organizations are likely to want to store extra data on the limits of ‘producability’ alongside each material and geometry.

Table 5 – Examples of process and geometry information that is unique to composites

<table>
<thead>
<tr>
<th>Item</th>
<th>Additional information &amp; links</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laminates</td>
<td>Processing parameters – layup, manufacturing route, cure cycle</td>
</tr>
<tr>
<td></td>
<td>Physical properties – areal weight, $V_f$</td>
</tr>
<tr>
<td></td>
<td>Quality data – NDT information, pictures…</td>
</tr>
<tr>
<td></td>
<td>Links to: associated materials, intermediates, test records…</td>
</tr>
<tr>
<td>Assemblies</td>
<td>Geometry data</td>
</tr>
<tr>
<td></td>
<td>Processing – e.g., details of cure cycle parameters for adhesives</td>
</tr>
<tr>
<td></td>
<td>Links to: materials used, sub-elements or laminates, test records…</td>
</tr>
</tbody>
</table>

3. Specifying a composite data management solution

So how do we specify a composite data management solution? In this section, we first examine alternative approaches to creating such a system, and then itemize some specific requirements.

3.1 In-house v ‘COTS’ solutions

There are two fundamental routes available to materials engineers specifying a system for composite data management. These are to purchase a ‘commercial off-the-shelf’ (COTS) system or to develop a system via an in-house information technology project. There are also options between these two ends of the spectrum, in which a third-party provides some relevant information technology and then delivers consultancy services to customize this and build an in-house system.

The Material Data Management Consortium has elected, as far as possible, to follow a ‘COTS’ approach – maximizing the amount of off-the-shelf software that is common to all users, and minimizing the amount of customization required. Why is this?

- **Expertise.** Building materials information systems requires an unusual blend of materials engineering and information technology expertise. Engineering enterprises want to focus on their core competences, not on building up and retaining a critical mass of expertise in this area. The MDMC has elected to work with Granta Design, a specialist materials information technology company.
- Sharing best-in-class technology and costs. A COTS system shares and re-uses core technology and solutions developed and proven elsewhere, whereas an in-house approach must ‘re-invent the wheel’. This fact is at the heart of the MDMC approach, in which pre-competitive collaboration helps to develop and maintain software that is used by all of the membership – and available to other organizations in the GRANTA MI system. As well as getting a better end-product by pooling ideas and feedback from many users, this approach means organizations share the cost of developing the system, rather than bearing the full cost themselves.

- Cost of updating & maintenance. The most common reason for the failure of in-house projects (or those where the software requires a high degree of customization) is that the costs of maintenance and on-going development are greatly underestimated. It systems need to develop in line with new needs and must respond to changes in hardware, operating systems, or corporate IT policies. Such maintenance is usually built in to COTS approaches – particularly where an active user community sustains the system. It is rarely well-understood in either in-house systems, or those built with external contractors that rely on a high degree of up-front customization and development work.

So what are the drawbacks of a COTS approach? Obvious potential issues, particularly given the way in which most composite data is tied to the particular application in which the composite is used, are flexibility and adaptability. There is the risk that any off-the-shelf system cannot handle the particular hierarchy of information, data types, and analyses required by the user company. And there is also the risk that it will become its own ‘island’ of information, into which composite data can be read, but with a limited ability to make use of this data due to poor connectivity with the rest of the company’s IT infrastructure. The good news is that today’s best practice materials information management systems can overcome these potential barriers, allowing flexibility in the structure of their databases, and providing open integration with third-party tools. The message to anyone specifying such a system for composites is that they should ensure that these capabilities are built into the requirements for their system.

3.2 Requirements for a COTS solution

So, what requirements should be specified by any company looking for a commercial off-the-shelf solution for composite data management?

Here are 10 of the main requirements:

1. A single, easily accessible materials information source – a central database capable of capturing all relevant composite data (e.g., from testing, QA, and design), ideally with integrated access to relevant reference data. It should be accessible from the desktops of any authorized engineer.

2. Domain support – the database must handle the specifics of all types of materials and process data, including multi-dimensional property data, and those data types (composite components, mechanical properties, processing, producability…) specific to composites.

3. A flexible database ‘schema’ – this allows the system to adapt to the specific information that the company needs to store.

4. Speed and scalability – the ability to manage high volumes of data in order to capture the full process and testing history of every composite used by the company.

5. A relational structure – this allows the system to capture and maintain links between objects in the database.

6. Support for ‘traceability’ – tools that exploit the relational database structure and automatically create links between related objects as they are imported or created. For example, the system could be configured so that when creating a composite record, it is automatically linked to records for the constituent matrix and reinforcement materials.

7. Specialist tools to import, export, and manipulate data relating to composites – e.g., to import data from specific test machines and analyze sets of data to generate design data.

8. Ability to integrate with other software – e.g., to embed in-house analysis tools within the system, or to pass materials property data directly to CAD and CAE systems.

9. Enterprise data management capabilities – e.g., capture the full history of changing data records and control who can access which records or data.

10. Data quality notification systems that highlight the applicability of data – e.g., is it ‘A Basis’ design data, manufacturers’ data, or data extracted from a website.
4. The GRANTA MI solution

4.1 Some key features of GRANTA MI

GRANTA MI is the leading system for materials information management in engineering enterprises. At its heart is a database system, installed on a server for enterprise network or web access. The database is explicitly designed to manage specialist materials and process information. It can host in-house data, external reference information, or a combination. Many types of data can be stored. Examples include:

- Single-point data – for simple property values
- Graphs, grid, series data – for ranges of data
- Multi-dimensional data with many variables – enabling, for example, capture of stress-strain curves for a material at multiple temperatures
- Equations and logic – data is determined by applying stored expressions or logical statements. This supports: automatic calculation of properties based on other data in the system; storing complex materials models; plotting design curves based on these models
- Documents and media files – spreadsheets, photomicrographs, PDF documents, movies...
- Unit systems – store and switch between data in US, Metric, SI, Imperial, and other systems

A typical dataset handled by GRANTA MI describes several thousand materials, each having thousands of associated property curves representing multiple conditions and temperatures. Generic information systems, and even most materials databases, simply cannot manage the full complexity of specialist data such as this.

Data can be imported from text files, Excel spreadsheets, and the output files of standard materials testing equipment. The data import tools are quick and easy to configure so that they can capture a company’s own file formats or test output.

The data stored in the system can be quickly browsed, queried, analyzed, plotted, and used through a simple web browser interface, as shown in Figure 4.

Further features make GRANTA MI appropriate for enterprise data management, and also provide key capabilities for composite data management:

- ‘Meta-data’ – the ability to capture and store ‘data about data’, so that the context for information can be recorded
- Traceability – related data can be linked; ‘smart linking’ automates this process

Figure 4. Composite data in GRANTA MI. The left-hand pane allows users to navigate a ‘tree structure’ of records for materials and test results. The right hand pane displays data for the chosen laminate record. Records, and individual items of data within them, are hyperlinked to related items elsewhere in the database.
• Scalability – the system handles large volumes of data and many users across an enterprise

• Access control – for whole records or individual items of data, this provides security and ensures that users only see information appropriate to their role (e.g., designers only see ‘approved’ design data)

• Version control – ensures control and recording of changing information

• Data quality ratings – allows data to be flagged so that it is used for appropriate applications (and not used inappropriately)

• Integration with other software – MI:Gateway technology allows third-party software (e.g., CAD and CAE) to access data directly within GRANTA MI (more information in Section 4.4). An application programming interface allows third-party or in-house tools to be embedded within the GRANTA MI interface.

Between them, these features deliver most of the requirements outlined in Section 3.2 for effective composite data management. But what makes the system particularly suited to composites are the ability to configure it to capture the relationships between data, and its flexibility in adapting to the needs of a specific company. These features flow from the way that the so-called ‘schema’ is specified.

4.2 A flexible schema

The relational structure of GRANTA MI allows data to be stored in one location and to be referenced (or copied) elsewhere. The key to success in setting up a composite data management system is to define the types of data that need to be stored, and the relationships that exist between them – for example, that one possible class of material we will want to store is *laminates*, and that laminate records will typically link to records describing a *matrix*, *reinforcement*, and a *ply-layer architecture*.

This ‘map’ of the database is known as the *schema*. The schema defines the types of data to be stored, the attributes of each type, relationships between them, and operations that can be performed upon these objects. Getting the schema right is an essential and difficult task. GRANTA MI provides template schemas, including one defined by the Composites Sub-Committee of the Material Data Management Consortium, illustrated in *Figure 5*. Each of the smaller boxes represents a ‘data table’ – part of the database configured to store one particular aspect of the company’s materials information. The lines indicate which tables, or groups of tables, are directly linked.

This detailed schema (illustrated only at an overview level in the figure) is a valuable resource, providing new users with clear guidance in configuring their database. It represents the collective wisdom of MDMC members, and often works with little further adaptation.

A key point about the schema, however, is that it *can* be adapted. It is relatively easy to ‘tweak’ in order to represent an individual company’s materials, data gathering requirements, and way of describing their composite materials.

4.3 A case study

Discussions of software features and database schemas can be rather abstract. The best way to illustrate their value is with a case study. A number of organizations are managing composite data using GRANTA MI. But the data that they are managing is, of course, confidential. So, in order to illustrate how the system works in practice, we have taken data from the AGATE...
program. This data is available as a reference data set to any user of GRANTA MI. But here we use it to show how such users might manage their own in-house data.

The key items of data required to describe a particular composite within this data set are showing in Figure 6. The focal point is the laminate panel. Each laminate is given an identity when manufactured. In our example we are interested in panel “A1-910_058_0°tens_S.”

![Figure 6 – Key items of data describing a composite in the AGATE data set.](image)

The record for the laminate contains all of the data regarding the processing parameters and cure steps taken to create the laminate, including stacking sequence and cure cycle, as well as raw data about the laminate itself, such as density, thickness, $V_t$ and volatile content. We see this in Figure 7 (overleaf).

Most materials characterization projects require statistically-backed data to be calculated from a range of laminates made from different batches or suppliers of prepregs or other constituent materials. This allows any variations between the manufacturers to be highlighted. In our example, the laminate was manufactured from prepreg materials from batch AF991011. The link to the record for the prepreg is highlighted on Figure 7 and this record is shown in Figure 8. Note that it is possible to add further rows representing additional layers to the “Lay-up sequence” table in Fig 7, enabling hybrid composites and sandwich panels to be handled.

The record for the prepreg gives information including the reinforcement and matrix used and the date of manufacture. Note that the schema for this database includes many more attributes than those listed. This is necessary to ensure systematic data capture. But all of these attributes are not required in order to create the pre-preg record. In this case, attributes such as green stage cure and $T_g$ are missing and so are not shown. But they can easily be updated once the relevant data becomes available. The prepreg record also shows full traceability to individual records for the raw matrix materials (batch identity, viscosity, gel-time, density, etc.) and the fibers (pre-cursor, tow twist, fiber tow count, etc.).

Returning to the laminate record (Figure 7) we see that, once fully conditioned (and with that data captured in the system), laminate specimens were tested. Links to data from each test are at the foot of the laminate record. This allows the conditioning for each specimen to be stored individually, and also accommodates multi-part tests such as compression-after-impact (CAI). An example record for the raw test results from a specimen cut from out laminate is shown in Figure 9.

The next step in a materials characterization exercise usually concerns the generation of a statistically relevant data population and its analysis for a characteristic or trend. In our example, the in-plane elastic properties in tension and compression have been examined, and the data is stored in a summary record shown in Figure 10.

The data in this record shows the statistics of the measured population, along with general pedigree data, and links back to each of the raw test records used in the analyzed population. Easy traceability from the statistical data back to all raw data enables a number of important use cases to be supported. For example, the results of analyses using different statistical methods can be compared if the population used for each is the same, and easily retrievable. Alternatively, the same statistical methods can be applied to a different data population in order to identify any change in performance over time, or to understand the effects of changing different processing parameters.

In summary, the schema allows statistical data to be linked to all raw test data in the populations that they represent. Each of the raw test data records, containing any conditioning information, is linked to the laminate record where the information about the process history and cure data is held. The laminate record is linked back to any preform used, such as prepreg, which is in turn linked back to data for each of the raw constituent materials. This whole process can be automated. And it could be extended, enabling data storage for more process-intensive materials manufactured in multi-stage processes. Alternatively, the schema could be reduced for more straightforward manufacturing process.
Figure 7. A typical datasheet showing the process history of a laminate with links out to any prepreg used and the raw test data.
Figure 8. A record showing data for a batch of pre-preg material.
Figure 9. An example of raw tensile data.

<table>
<thead>
<tr>
<th>Project Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project name</td>
</tr>
<tr>
<td>Project code</td>
</tr>
<tr>
<td>Location</td>
</tr>
</tbody>
</table>

Figure 10. Part of a record containing statistical summaries of tensile test data available for a laminate.

<table>
<thead>
<tr>
<th>Test temperature</th>
<th>82.2 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range attributes</td>
<td></td>
</tr>
<tr>
<td>Fiber volume</td>
<td>1.49 ± 0.15 mm²</td>
</tr>
<tr>
<td>Ply thickness</td>
<td>0.196 ± 0.025 mm</td>
</tr>
<tr>
<td>Resin content</td>
<td>35.10 ± 0.45%</td>
</tr>
<tr>
<td>Void content</td>
<td>5.44 ± 3.57%</td>
</tr>
</tbody>
</table>

Link to summarized test data (Figure 10)
4.4 Analytical and model data for CAD and CAE

Our case study has shown how the GRANTA MI system meets the needs of composite data management – capturing the relevant data and all of its relationships, storing this data, managing it, and providing easy, controlled web browser-based access. Before concluding, however, it is worth considering one important way in which this data is actually used.

The end-users for most materials data are design and analytical engineers working on the next generation of products or components. They need materials data in the format required by their analytical or design tools. The reformatting of this data to suit more elementary analysis types is straightforward. However, there have been many developments in modeling software that require “input decks” for analytical software to include much more information about materials and their properties – often in excess of 20 or 30 parameters. These developments provide the ability to combine all aspects of a material’s use, for example:

- thermally-induced residual strains from multiple processing steps, accounting for gelation and the calculation of residual strains
- load distribution from in-service conditions and loads (and the use of “simple” failure criteria, e.g., Tsai-Hill\(^1\))
- damage mechanics (including standard implicit and explicit methods) using techniques such as matrix cracking initiation and growth, delamination, or volumetric damage models.

And we can add to this complexity the need to support different element formulations within and between the different finite element codes commonly used in industry\(^2\). Just the recalculation of the model parameters required by some of the materials models in these codes can be a complex undertaking.

GRANTA MI and its integration capabilities can really help. The GRANTA MI data schema is capable of storing all of these data. Through the GRANTA MI:Gateway technology, the data can be passed directly to the analytical engineer, without the need for those engineers to leave their analytical software environment, or to learn a new tool – in fact, the engineer may not even know of the existence of GRANTA MI. GRANTA MI:Gateway allows a tool to be embedded within third-party software (e.g., an analytical system) that can access and apply data directly from a GRANTA MI database, as shown for Abaqus/CAE in Figure 11. In the figure, the smaller window has been opened from within the CAE system’s menus. It lists the contents of the corporate materials database, and has allowed the user to open a datasheet on a particular material. Data from this datasheet can then be imported for use in modeling.

So, for example, fully traceable model coefficients stored in GRANTA MI could be extracted directly and applied within an FE tool. MI:Gateway tools can be built by in-house staff or the Granta services team – or they are available ‘off-the-shelf’ for a number of widely used CAD and CAE systems.

4.5 Composite reference data

Our major focus in this paper has been on the management of in-house composite data. But the system described also has the advantage of making it
much easier to access and use reference data sources. Among the reference data that is currently, or will soon be, available within GRANTA MI are:

- **AGATE**³ – composite design data created as part of the (now complete) NASA-sponsored AGATE project (AGATE data was used as a proxy for in-house test data in our case study in section 4.3)

- **CMH-17**⁴ (formerly Mil-Handbook-17) – over 1,000 records of test data for polymer matrix, metal matrix, and ceramic matrix composites.

- **NCAMP**⁵ – data from the National Center for Advanced Materials Performance, an on-going effort to generate composite property data

- **IDES Composites**⁶ – data from a leading source of information on plastic materials

- **MaterialUniverse**³ – Granta’s generic materials property data, enables comparison between composites and other material classes (e.g., as in Figure 1).

By providing this information within the GRANTA MI system, not only can companies ensure a single, integrated source for all of the composite data that they need – making it much easier to find – they also make that data searchable and easy to access, either through the web browser interface or, via MI:Gateway, within their CAD and CAE software. Fully digitizing the data within GRANTA MI also makes it much more usable – for example, property values are available as ‘live’ numbers, not simply text in a PDF document, enabling users to query the data meaningfully. Design curves are also ‘live’ so that they can be used to extract numbers quickly for a material property under specific conditions.

5. Conclusions and next steps

Good materials data management can yield considerable returns to engineering enterprises and materials producers. Composite materials add complexity, making it more difficult to implement data management, but also magnifying the value of implementing best practice in this area. We have discussed the difficulties, identified the features of a materials data management system that are required to overcome these difficulties, and shown how the GRANTA MI system provides these features.

GRANTA MI is the industry-standard solution for materials data management. It provides the necessary infrastructure for composite data management. GRANTA MI has been developed in collaboration with the Material Data Management Consortium to meet the exacting needs of member organizations such as Boeing, Rolls-Royce, NASA, GE, and Honeywell.

Granta is available to work with any engineering enterprise in order to apply GRANTA MI for composites. We are also a member of the European Union MANUDIRECT project⁵ which is developing new methods for manufacturing of composite materials. Granta is providing a database system to store and share project data between the 18 commercial organizations and universities that make up the project, and tools to predict the properties of hybrid materials.

If you are interested in how GRANTA MI could assist your management of composite data, please contact us using the information on the front of this paper.

References


5. NCAMP – The National Center for Advanced Material Performance, at the National Institute for Aviation Research, Wichita State University, KS, USA, [www.niar.wichita.edu/coe/ncamp.asp](http://www.niar.wichita.edu/coe/ncamp.asp)


12. V.D. Azzi and S.W. Tsai, Experimental Mechanics 5 (1965)
