

Through-life data management for composite material products

N Swindells

Ferroday Ltd., Mere Farm Road, Birkenhead, CH43 9TT, UK

E-mail: norman.swindells@ferroday.co.uk

Abstract. The management of digital engineering information throughout the life cycle of an engineered product can be achieved by the representation of this information in information models specified in International Standards. The fundamental basis of this technology is described and its application to the design and manufacture of composites is outlined. The use of ISO 10303-235 'Engineering properties and materials information' for the representation of data from the testing of composite coupons and for the ultrasonic non-destructive evaluation of defects is described as an new example of this technology. The benefits of these standards for the quality control of the information and their role in its conservation are briefly described.

1. Introduction

Throughout the supply chain and the life cycle of an engineered product there is the need for the transfer of digital information about the product between different software systems, each with its own internal method of representing the data. Figure 1 is an attempt to illustrate this life cycle. Digital interoperability between different systems therefore requires a method to ensure that the data in the message from one system can be understood and used by the receiving system. For the long life times of products, such as in the aerospace sector, the digital data also needs to be conserved and yet be still understandable and usable when the originating software is obsolete or no longer available.

The management of engineering information throughout the life cycle of a composite product therefore requires cooperation between several different software systems each with a different role and operation. In an analogy of cooperation between humans from different nationalities, such cooperation requires either pairs of translators between each of the different languages or an agreement to use a common language. The number of translators needed for n individual systems is $n(n-1)$ and so the number of translators required rapidly becomes unsustainable in large networks of systems. All software systems use a proprietary internal information structure and a local internal dictionary and it would be more efficient and economical if all the members in a communication chain used a common language, based on a common information structure and a common dictionary. The solution adopted by the global engineering profession was therefore to develop a standard information structure for the *external* exchange of the data and a standard structure for a dictionary. This solution effectively provides a common language to promote interoperability and cooperation between different engineering systems.



A solution to digital interoperability was identified as being necessary because of the global expansions of the supply chains for the main capital industries. These requirements arose almost simultaneously in all the main industrial nations and there has been a corresponding global response with a high degree of collaboration and mutual understanding to resolve the problems that were identified. However, the use of the technology has remained a preserve of a few companies and industrial sectors and there has been limited awareness and adoption by a wider population. A recent report from the Strategic Standardisation Group of the Association of Aerospace and Defence Manufacturers of Europe (SSG-ASD) is titled: *“Through Life Interoperability – A critical strategic lever for competitiveness”* [1]. The Group’s vision for through life interoperability is that “All players in the aerospace value network will be able to share digital information securely throughout the life of the products and services”. The report recognizes the value of standardized information models for product data representation and exchange for this role and intends to make these standards the cornerstone of this interoperability. Some of the standards for the representation of data for composite products on which this strategy depends are described in this paper and an overview of the technology and more information in its applications has been published [2].

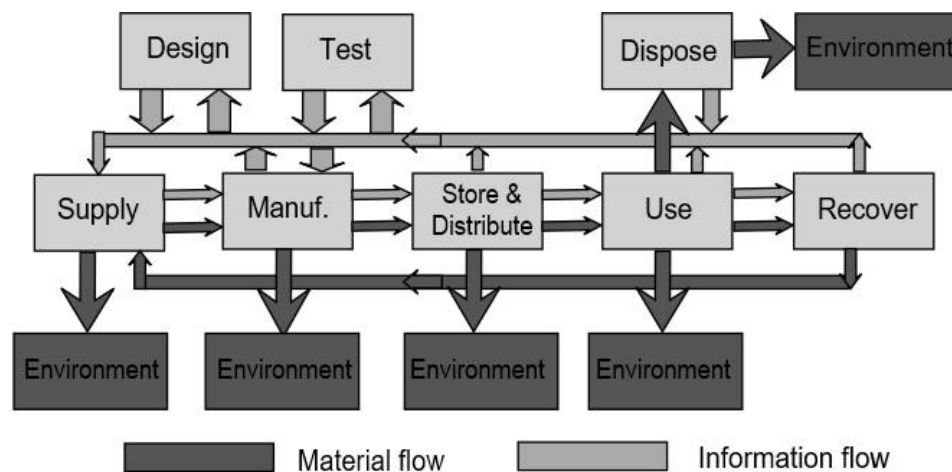


Figure 1 Illustration of the flow of information through a product life-cycle
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2. Standardised information models

The solution for interoperability and information conservation of product data adopted by the aerospace, automotive, defence, construction, machine tools, process plant, offshore oil & gas and other sectors is to represent the product data in non-proprietary, computer-understandable information models. The models are specified in a series of International Standards to provide a common language for the digital representation of engineering information. These Standards have been developed since 1984 within the ISO Technical Committee 184, Sub-committee 4 (ISO/TC 184/SC4) in a collaborative effort by hundreds of engineers from the main industrial nations and most of the global industrial sectors. The models are written in the EXPRESS computer processable language [3] standardised in ISO 10303-11 and look like object oriented computer algorithms.

Information models in the ISO 10303 family of standards are of two types:

- Integrated Generic Resources (IGR) – a representation of the basic concepts of engineering and manufacturing in a single generic information model;

- Application Protocols (AP) – selections from and extensions of the generic model to represent specific industrial situations. It is an AP that is implemented in, or interfaced to, engineering application software for real-time processing, communication and archiving of the data.

The information models are developed by very rigorous, formal methods to describe, in a computer processable form, aspects of the real world of manufactured products, manufacturing processes and their properties. In effect, they provide engineering specifications for this data with the important benefit that they are independent of proprietary software. These specifications can also be used as the basis for quality control and quality assurance of the engineering data, just as with any other engineered product. The additional value of these information models is that they conserve both the syntax and the semantics of the data, ensuring that the information that the data represents can still be understood and interpreted correctly in the future even if the originating software is no longer available. They have been used for the representation of engineering data for over 20 years and the reliability of this representation has been proven many times.

Some aspects of the scope and application of some of the standards that are relevant to the life cycle of composite materials products are summarized in the following sections.

3. Design and manufacture of composite material products

Hunten [4, 5] has described the application of ISO 10303 standards to the design and manufacture of composite material products. The problem of integration of information between shape design, analysis and manufacture is made more difficult when the product is made from a composite material structure. Most production systems currently employ specific point-to-point translators to enable this transfer of information, and very few analysis systems are able to return geometric shape information seamlessly to the design shape modeler. With composite structures there are the additional problems of calculating true fiber directions and ply flat patterns that are shared with the manufacturing process. All of this information needs to be shared with commercial or in-house detailed analysis codes such as those for fastened joints and panel buckling. The interconnections required between design, analysis and manufacturing information for a composite product are illustrated in Figure 2.

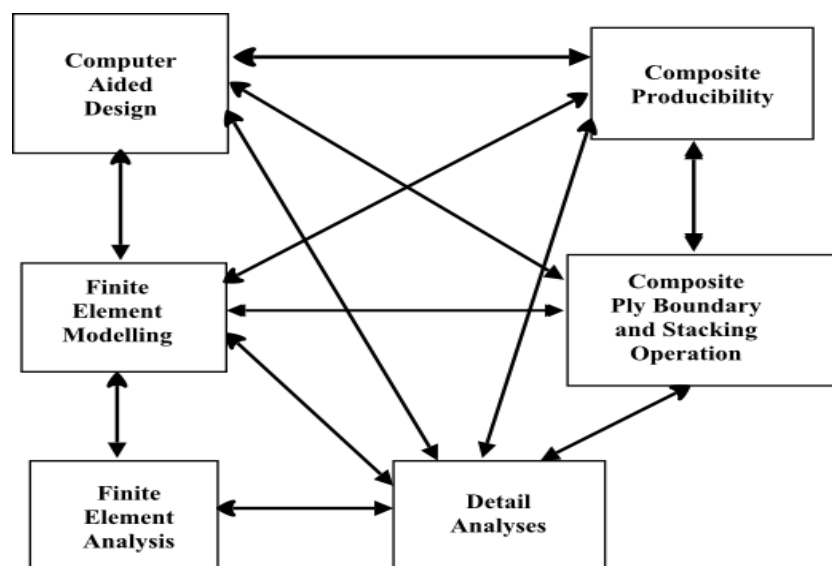


Figure 2. The interconnection of design, analysis and manufacturing information
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Edition 1 of ISO 10303-209:2001 Composite and metallic structural analysis and related design (AP209) was developed in ISO TC184/SC4 to enable companies using different CAD and FEA systems to exchange engineering design and analysis data using standard file formats. Configuration management data within the standard can ensure that design and analysis information carried out by the different teams relate to the correct product versions. A company will be able to archive associated, configuration managed CAD and FEA data in the AP209-format with confidence that the data can be reused in the future whatever changes of systems have occurred.

The information model of Edition 1 of AP209 provided resources to describe the following main concepts:

Finite element data: This includes models, analysis definitions and load cases, and results. A model can be specified in as much detail as required – if necessary down to the level of element shape functions, discretisation points and integration rules. Static and natural frequency analyses are within the initial scope.

Configuration management data: A version of the finite element model is linked to a version of the product. This ensures that the correct finite element data may be associated with the correct version of a product within a Product Data Management (PDM) system.

Product geometry: Both the design geometry and the idealised geometry created for analysis can be recorded. Nodes, finite elements, their edges, faces and volumes can be explicitly associated with aspects of the product geometry. It is possible to specify element properties, loadings or boundary conditions on a curve, edge, surface, or volume of the geometric model.

Composite lay-up: The lay-up of a composite part can be specified in detail. Shape, stacking sequence, and property information can be supplied for individual plies and their fibre orientations.

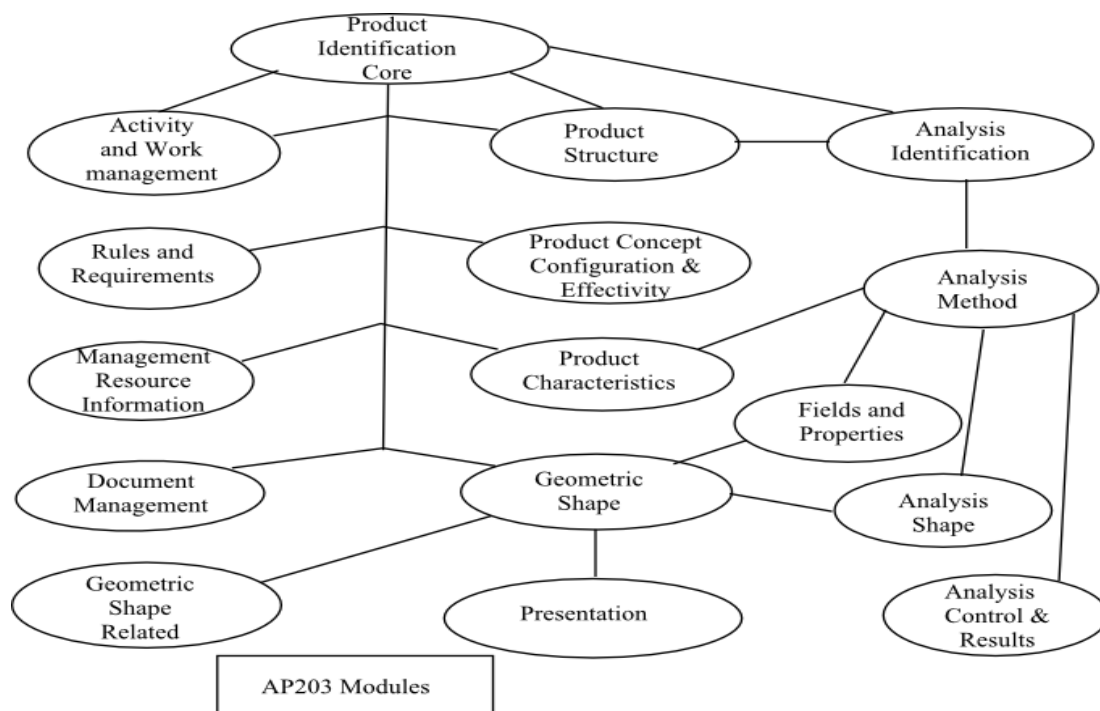


Figure 3. A high level overview of ISO 10303-209 edition 2
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The second Edition of ISO 10303-209:2014 (AP209 ed2) – now renamed Multidisciplinary analysis and design [6], has added a generic Engineering Analysis capability complimented by specific Computational Fluid Dynamics (CFD) and a generalized mesh based numerical analysis capabilities to the classical Finite Element Analysis capabilities of AP209 Edition 1. The intention is that AP209 ed2 will now address a much wider set of multi-disciplinary analysis and optimization problems. A high level overview of AP209 Edition 2 is shown in Figure 3.

Edition 2 of AP209 has also been incorporated into the new development of ISO 10303-242 Model-based 3-D engineering.

4. Engineering properties and materials information

Ferrodag Ltd is responsible for the development of two information models in the ISO 10303 series. ISO 10303-45: “*Material and other engineering properties*” is a part of the IGR and is a generic information model for the representation for any property of any product and its value, including the chemical composition [7]. ISO 10303-235: “*Engineering properties for product design and verification*” is an AP that extends the IGR to represent the collection of processes by which the value of any property of a product is obtained [8]. The scope of ISO 10303-235 is summarised in Table 1.

Table 1. Summary of the scope of ISO 10303-235

Technical	Administrative
Products, product history	Persons, organizations, addresses
Properties of products and resources	Approvals, qualifications, certifications
Processes and their properties	Dates, times
Numerical and descriptive values	Documents and files
Mathematical expression values	External references
Uncertainty and reliability of all values	Effectivity
Product substance composition and structure	Language
Dimensional and positional tolerances	Locations
Resources	Requirements

The principal concepts on which ISO 10303-45 and ISO 10303-235 are based are:

- All ‘materials’ are products produced by a process and so can be represented by the information models for products and processes developed by ISO/TC 184/SC4.
- The process used to determine the value of an engineering property of a product defines its meaning (semantic).
- The magnitude of the value of an engineering property will be dependent on the characteristics and operation of the measurement method and on the characteristics of the product.

As examples: most property values vary with temperature, some property values depend on the dimensions of the product; the value of the tensile strength of a metal depends on the rate of the extension of the load applied during the test. The collection of characteristics and their values that have an influence on the value of an engineering property are represented by the data environment, defined in ISO 10303-45, and these need to be associated with the property value in order to conserve the semantics of this value.

There are many processes that are used to determine the engineering properties of a product and they vary between different national industrial systems. It is therefore not practical to include the names and definitions of measurement processes and the names of their properties in the information

model of ISO 10303-235. ISO 13584 *Parts libraries* defines an information model to provide a dictionary of terms and their definitions and ISO 10303-235 can make a reference to this external source to obtain these names. Kafka [9] has shown that a dictionary of testing processes and their related properties can be developed from these principles.

It was discovered in the development of ISO 10303-235 that there is a level of abstraction that enables all measurement processes to be represented by instances of the same information structure. So that, combined with the capability to reference a dictionary for the names of the measurement processes and their properties, ISO 10303-235 can represent any property of any product measured by any method.

5. Applications of ISO 10303-235

5.1 Method

For the representation of data for each of the examples of applications of ISO 10303-235 the procedure followed a series of stages:

1. The starting information would be in the form of a data sheet or other document describing some of the details of the measurement method, the details of the equipment used and the results.
2. The document form of the information was represented by a high-level information model using EXPRESS-G, the graphical form of EXPRESS, in order to ensure that all of the information in the starting document was accounted for and could be understood.
3. A *view*, or portion, of the standard model was then created by software to form a template for the representation of the information in the high level model. The relationship between the data items in high-level model and the items in the view of the standard model was confirmed by documenting the mapping relationship between them. The template view of the standard model can then be managed by the TenDEX® software developed by Ferroday Ltd to enable the input of the data for the application.
4. The TenDEX® software can be configured to present a data sheet for the input of data into the standard structure that corresponds to the real world example in stage 1. Inputting data into the template via the software automatically creates a data file as an instance of the template model. The format of this data file conforms to ISO 10303-21 and conserves the information structure of the standard model as well as the data values in those parts of the model that were selected to represented the real world results. The template can be reused each time the test or investigation is carried out.

5.2 The testing of composite coupons

The testing of coupons extracted from sheets of prepared composite materials is a starting point for the life cycle of a composite product. The preparation of these sheets for aerospace materials and the manufacture of the coupons from these sheets is governed by European and aerospace standards. Following the method outlined in 5.1, above, a selection of relevant sections of ISO 10303-235, forming a view of the standard as a template, was able to represent the testing of five coupons manufactured in this way for both tensile strength and buckling by compression between two grips. This view of ISO 10303-235 was able to record the history of the process of manufacture of the test specimens by reference to the appropriate standards, the characteristics of the testing machine and the conditions of its operation, the values of the properties and the statistical evaluation of the results.

5.3 Ultrasonic non-destructive evaluation (NDE)

The results of a non-destructive evaluation of a product for internal defects depend on the settings of the control instrument, the characteristics of the ultrasonic probe and the capabilities and level of competence of the operator. Interpretation of the engineering structural integrity of the product requires a detailed description of the product and there may be more than one product joined together

in the structure being tested. Applications of ISO 10303-235 were created, following the method outlined in 5.1, above, to represent all of the details of three products and their ultrasonic NDE inspection by the methods of phased array, pulsed echo and time-of-flight diffractometry (ToFD) respectively. Views of ISO 10303-235 were developed for each of these use-cases to provide templates for the input of the characteristics of the product, the control instrument and the probe and a record of the locations of the defects that were detected. The qualifications and certification of the operator could be represented as well as the qualification and certification of the supervisor who specified the method to be used and the details of the verification of the process and the results.

6. Quality control and quality assurance of product information

With the change to all digital representations of engineering information there is a critical need to ensure that the data that represents the information can be relied upon, that it is supplied to agreed specifications and meets the needs of the users. These are the concepts of quality assurance of any product, which should be supported by formal methods of quality control of the information by the supplier – just as with any other engineered product. They are of greater importance when the data has to be conserved for the whole life cycle of a product. The requirements for the quality control and quality assurance of information and data are being specified with the development of ISO 8000 – Information and data quality. ISO 8000 Part 8: *Concepts and measuring* [10] provides:

- Definitions of the quality of information and data;
- A structured way to plan measurements of the quality of information and data;
- Pre-requisites for measuring the quality of information and data;
- Requirements for reporting measurements of the quality of information and data.

Information is defined by ISO 8000-8 as: “*Knowledge concerning objects, such as facts, events, things, processes or ideas, including concepts, which has particular meaning within a certain context.*” Data is defined as: “*Re-interpretable representation of information in a formalized manner suitable for communication, interpretation or processing.*” Metadata is data that describes and defines other data. A *conceptual model* is the model that describes concepts of a universe of discourse.

Three types of quality are defined for information and data: *syntactic*, *semantic* and *pragmatic*. These concepts are intended to apply to any information and data. Swindells [8] has shown how the standards developed in ISO/TC 184/SC4 conform to the recommendations of ISO 8000-8.

7. The conservation of digital data

The conservation of digital data in an archive will be necessary to manage the information from the composite product throughout its life. This requirement is common in all sectors where the information is now mostly created and processed digitally. This common requirement can be managed by a procedure originated by NASA for its space data and now adopted by ISO and standardized as ISO 14721 [12]. The procedure is known as the Open Archival Information System (OAIS framework) and has six stages:

1. *Ingest* – input data records plus the metadata to enable them to be found in the future;
2. *Data management* – ensure quality control and quality assurance of the input;
ISO 10303 specifications can provide the basis for quality control;
3. *Storage* – physical storage of data including back-up and migration to new media;
4. *Preservation planning* – ensuring the data is not just a stream of unreadable digital bits when future access is required and the original software and systems are no longer available;
ISO 10303 standards conserve the semantics as well as the syntax of the data;
5. *Access* – finding records in the archive and distributing them to appropriate users;
6. *Administration* – operation and maintenance of the archive.

Note that the second and fourth stages will benefit from the use of the standard information models from ISO/TC 184/SC4.

8. Discussion

The main aims of this research were to demonstrate that the global knowledge base provided by the information models in the ISO standards for data representation and exchange can be applied to the representation of real engineering information for composite material products and also to develop ways to reduce the barriers to their use. The standards from ISO/TC 184/SC4 do not provide any indication of how they may be used as an application for an industrial information representation that is within the scope of the standard. The technology of these standards is at the interface between deep knowledge of an industrial engineering situation and the understanding of modern software and information modelling. Very few engineers possess this combination of knowledge and experience and most would not have the time, the opportunity or the wish to acquire it, however, they would want to be able to verify that the computer representation of what could be critical information is accurate and relevant for their needs. The method described in this paper of generating a view of ISO 10303-235 as a template for the input of data for a particular application provides a way of validating that the standard model can represent a real application. The high level-model representation of the original data and the documentation of the mapping onto the template derived from the standard model could be sufficiently concise and clear to enable users to review their scopes and confirm that the template meets their needs. A template derived in this manner could be re-used many times for the input of data from a series of the measurement processes that it represents.

ISO 10303-209, and its incorporation into ISO 10303-242, is intended for use at the design stage of the composite material product. The subsequent stages of the life of the product will be monitored by successive measurement of the properties of the product that are appropriate for the stage of life. Since ISO 10303-235 can be used for the representation of the combination of product, process and property data, this standard can be used for recording the status of all of the subsequent stages in the life including monitoring the structural integrity by NDE. Applying the principles established in ISO 8000-8 should ensure that this series of property data records could be relied upon to provide a history of the product and an audit trail for the source of engineering information for the whole life cycle of the product. The OASIS framework provides the means to ensure that the data will still be available for use in the future.

9. Conclusions

The digital representation of engineering product, process and property information based on the global knowledge in the standards from ISO TC184/SC4 is:

- *Comprehensive* – applicable to all engineering activities;
- *Expandable* – able to cope with new types of products and processes;
- *Scalable* – able to represent small and large data sets;
- *Sustainable* – independent from proprietary software;
- *Dynamic* – in continuous development to match new developments in IT methods and resources;
- Supports improved interoperability and quality assurance to reduce costs.

The application of this technology to the representation of data for composite products has been proven with both ISO 10303-209 and ISO 10303-235 and these standards should be adopted more generally by this industry sector.

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