A CONCEPT FOR THE COLLECTION AND PRESENTATION OF MATERIAL PROPERTIES FOR DIVERSE APPLICATIONS

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Abstract

The notion of matereality is defined: a collection of material properties that quantifies the behavior of a product under conditions it will see at any given stage of its life cycle. The interrelationship between matereality and PLM is explored and key defining elements are offered to solidify the application of matereality as a basic unit of material data management (MDM) and its application for distribution and use of material properties within and across enterprises.

Introduction

There are a large number of materials available to the product developer in the world today. These include metals, plastics, rubber, foam, ceramics, glass, paper and composites of these materials. Additionally, for many modern product environments such as automotive interiors, materials such as adhesives, fabrics and carpet materials must also be considered. Most of these materials exhibit complex, interdependent behavioral characteristics that vary with the environment that the product sees at any particular stage of its life cycle. Understanding this response is critical to the development of the product. Failure to do affects product performance, so that in limiting cases, badly designed products will not survive some stage of their life cycle. A high level of interdependency of behavior combined with cost issues prevents the development of a comprehensive behavioral map of a material's behavior. Thankfully, such an effort is usually unnecessary for the development of a particular product. It is adequate to understand material behavior in the context of the product's reality. The same material may however, present a different behavioral reality depending on its use in the product and even depending on the stage of the life cycle under study. These concepts in effect define a product's matereality, a collection of self-consistent material properties that describe the behavior of a product in a particular reality of its life cycle. The word itself is proposed from a fusion of the following word definitions:

material[f] **(ma· te· ri· al)**

> 1: the elements, constituents, or substances of which something is composed or can be made
>
> 2: matter that has qualities which give it individuality and by which it may be categorized

reality [f] **(re· al· ity)**

> 1: the quality or state of being real
>
> 2 a (1): a real event, entity, or state of affairs
>
> 2 a (2): the totality of real things and events
>
> 2 b: something that is neither derivative nor dependent but exists necessarily

yielding:

matereality (ma· te· re· al· ity)

> 1: a collection of material properties that realistically represents a particular behavioral reality in a product's life cycle

In this article, we seek to define and flesh out the concept of a matereality and its

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[f] Merriam Webster Collegiate Dictionary

significance in describing the behavior of a product during the different stages of its life cycle.

The nature of matereality

Physical properties are used to represent the behavior of materials in a variety of applications related to product development as well as at other stages of the product life cycle. Uses include engineering design, material specifications and approvals, quality assurance and product failure assessment. In each of these use cases, specific properties are selected to represent a particular reality that is important to the product at that particular stage. For example, it is common to use the melt flow index as a means to ensure the quality of a plastic from a flow/processing standpoint.

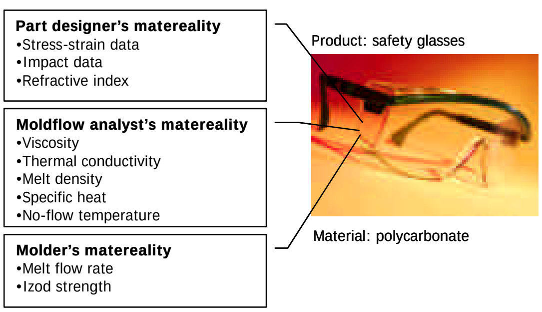

Figure 1. A product may expose different materealities to different people.

This simple measure permits shop floor personnel to easily establish the consistency of an incoming product. For this group, the melt flow index is their matereality. The situation is more complex in cases where a series of properties are measured, usually in response to a specification declared either by a client company, such as an OEM. Such submissions are the materealities of a materials supervisor, providing a unique standard of comparability by which many materials can be ranked for suitability for a particular application. Materealities of this kind are usually specific to a particular enterprise and possibly to the industry segment to which that enterprise belongs.

A more generalized case revolves around the use of a specification standard such as ASTM or ISO which allows for the creation of 'typical' properties; data found in material property data sheets and material property databases such as those currently offered over the Internet. These database properties being 'typical' in nature describe a particular reality in strict adherence to a national or international standard that permits the objective comparison of one material against another. They may say nothing about the true behavioral nature of the material. Such data are widely and correctly used as a first pass material selection tool for the design process and as such, represent a material selection reality for the product developer. They are often, however, incorrectly used to represent material behavior in engineering design and virtual product development (VPD).

Material properties for use in engineering applications such as product design and particularly VPD requires the generation of data that represent the behavior of the material in that particular application. This involves taking into consideration the realities the product sees and developing behavioral characterizations that capture that behavior. Such a matereality is typically composed of fundamental representative material properties that have been generated with minimal artifact.

For example, because they are sensitive to environmental moisture, it is common to condition nylons to equilibration in a 50% humidity environment to capture the loss in mechanical properties compared to the virgin material. Such properties are often found in databases and may be suitable in applications such as cable ties where the product is exposed to the elements. Here the database property represents the matereality of the product. If the same nylon is used in a fuel pump application, the stress strain behavior of the fuel soaked nylon are much more useful than the typical properties obtained from a test specimen subjected to standard conditioning. The same material presents a different matereality depending on the product application.

Now, in the above fuel pump application, it may be desirable to evaluate the stress-strain behavior of the fuel soaked nylon at a temperature of 60°C. It is known however, that physical limitations with the testing of materials will make such a test impossible. In this case, high temperature will evaporate the fuel from the test specimen so that the measured data no longer truly represent the behavior of the product in its application. Because of the complex interaction between the material and its environment, it is possible to approach but not capture all aspects of a products reality. Good testing methodologies enable us to get close to reality in VPD and then make real engineering judgments to account for the behaviors that have not been considered.

It is important to emphasize that the value of the matereality concept is not restricted to complex cases such as the above. For example the load bearing capacity of a computer housing may need simple stress-strain behavior at ambient, data that is readily available from some conventional material databases. It is important to introduce this behavior into the matereality of the product, as being the acceptable behavior for the computer housing, so that all people involved in its development will refer to the same behavioral definition.

To summarize, it is clear that the matereality depends on the material, the product and its stage in the product life cycle. Materealities may be simple or complex, depending on the application. Further, different entities in an enterprise may need different views of the same matereality to satisfy their needs.

Consistency in matereality development

A matereality needs to be self-consistent. For example a particular application may need to subject a product to loading over a temperature range between –40°C and 80°C. The matereality will need to account for stress-strain behavior. In the development of the material properties that comprise this matereality, it is important to develop the properties in a highly consistent manner. For example it may be expedient to combine previously available room temperature data with freshly tested properties at –40 and 80°C. This is risky unless the data has all been obtained from the same source or from sources of comparable quality. Differences in results from different sources can fracture the matereality so that it no longer represents the behavior of the material. Ways of ensuring comparability of data sources include the use of test laboratories that are accredited to ISO 17025, a rigorous quality standard that uses a range of measures to ensure precision and integrity of material data. These include detailed analyses of uncertainty, and the use of proficiency testing programs to verify that participating laboratories produce comparable test results.

Another source of inconsistency may arise from the source of test specimens. Variations in test specimens arise depending on a number of factors such as lot-to-lot variability and the method of specimen preparation. Such variations will affect the test results. If variations in the matereality appear due to inconsistent use of test specimens, the matereality is fractured once again.

The matereality of a product may need to define different types of behavior. In the above example, thermal expansion plays a role as the product cycles from one temperature to another. In order to ensure consistency, thermal expansion measurements must also be made in conformance with the rules presented above.

Accounting for variability

It may often not be feasible or practical to capture all nuances of a products behavior into its matereality. Variability in behavior can occur for a number of reasons. Lot-to-lot variations occur because of inconsistencies in the raw material and production processes. These variations have different implications for different stages of the product life cycle. At the product development stage, it may be adequate to have an in-depth consistent matereality and then simply understand the range of variation that can occur. In a production environment, a shallow matereality that monitors a few simple key properties is more realistic. In a failure situation, one reverts to the matereality of a particular product or production batch that is failing as compared to one which is good.

Another source of variability is that of spatial variations in behavior. This is a much more complex problem which is particularly observed in fiber filled plastics. Here, the orientation and concentration of fiber varies throughout the product resulting in extremely large variations in material properties. In a limiting case where it is possible to orient the fibers in a particular direction, there is maximum difference between the primary and secondary directions.

The importance of traceability

The properties that comprise a matereality must be traceable to an authoritative source. This allows for the objective assessment of the quality of the data for use in a particular application. (Figure 2)

(figure courtesy of Matereality LLC, * EMERGE is a trademark of the Dow Chemical Company)

Figure 2. Example of the kind of information needed to ensure traceability.

The choice of authoritative source depends on the stage of the life cycle that the matereality is being applied. In mission critical applications such as VPD, a lot of downstream effort rests upon the successful application of CAE tools to place a new product in a well understood production and use space. The ability to trace a matereality to a reliable authoritative source adds significantly to design confidence. For such applications, the appropriate reliable source could be a material supplier's laboratory, an internal lab or an external lab accredited to ISO 17025. Other materealities, such as those used to ensure product consistency, may be less stringent relying on ISO 9000 norms instead. In all cases, the matereality must include the knowledge of the source of the content.

Consistency in the use of matereality

A matereality must be shared uniformly and unambiguously among all parties that participate in a particular stage of the product life cycle. This is particularly important in the product development process. A large number of engineers may be involved in addressing different aspects of a product's development. Without the notion of a matereality, each engineer may have his or her own view of the behavior of the material used in the product, derived from his or her own search of databases and handbooks. The resulting properties may or may not adequately represent the product behavior depending on a number of factors including the availability of good data sources and the technical expertise of the engineer. Consequently, within the same product development group, different materealities of the same product arise. (Figure 3)

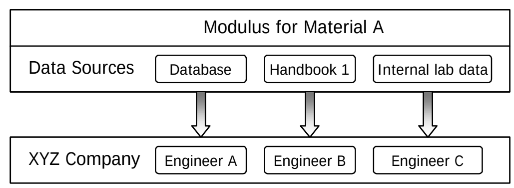

Figure 3. Example of fractured matereality from the use of multiple data sources.

Again, the matereality of the product is fractured increasing the likelihood of design defects. The problem is significantly aggravated in the current design environment where the product development group straddles different enterprises. A classic example may be an OEM who contracts the development and production of an automotive dashboard to a Tier One supplier who in turn may involve a consultant to help them with the VPD of the product. In the end, the virtual dashboard needs to be integrated into the virtual automobile for a full vehicle impact simulation. The consistent use of a single matereality across this entire development team will ensure that there is a singular representation of material behavior to all participants in this particular stage of the design process. Additionally, material suppliers may then create and present such a matereality for each candidate material and have it instantly applicable throughout this development cycle.

Matereality as intellectual property

A matereality becomes a valuable commodity to an enterprise and may be owned in much the same way as any other piece of property. Only those parties in the development and production of a particular product would typically have access to a particular matereality. There are two logical owners of materealities. Material suppliers may create a matereality that can be useful for all industries, for an industry segment, or even for a single particularly valuable client. Conversely, any enterprise may wish to develop and own a specific matereality that represents a particular behavior exhibited by its product in a specific stage of its life cycle. For example, an enterprise may use a material suppliers matereality to describe the flow properties of an elastomer in an injection molding simulation. Since the resulting product is used inside the human body, it will use its own matereality of properties at 37°C in a saline environment for the structural analysis of the product. The enterprise will typically wish to protect this matereality from unauthorized parties.

Conclusion

Materealities permit an elegant means to define and classify collections of material properties that can be used in diverse applications. A matereality is particularly useful in cases where the behavior of a material depends on a number of interdependent factors. The same material may have different materealities depending on the end use. Materealities are economical because they permit the generation and presentation of only the data needed to describe that application. Time to market is improved by eliminating the current inefficient search processes needed to find or obtain material properties for product development. Additionally, using an MDM system, the same matereality can be presented to all enterprises seeking to work in a particular application space Figure 4.

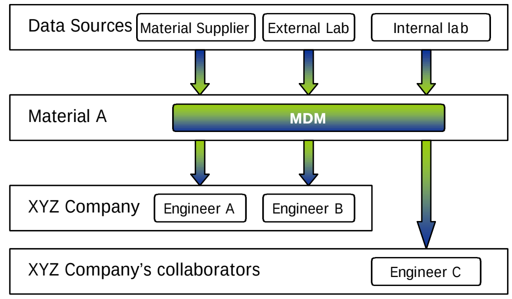

Figure 4. Use of MDM to store and serve materealities.

By permitting the proper description of material behavior, materealities provide major cost savings by improving design reliability and reducing the likelihood of product failure.