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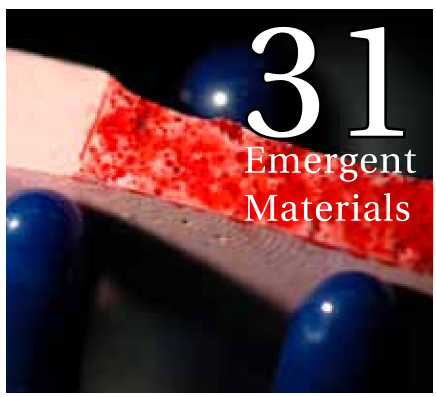

Messages:

On the cover:

The challenge facing researchers will be to develop advanced materials that will protect buildings from natural and manmade disasters while allowing designers to meet aesthetic, energy performance and sustainability goals.

An Advanced Materials Database: A Gateway for Future and Secure Infrastructures

The development of a new database to track advanced materials, their applications and their attributes will go a long way toward encouraging their use.

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THE DEVELOPMENT OF NEW MATERIALS has stagnated in past decades. The industry has been primarily driven by codes and standards, which establish minimum requirements based largely on industry performance and the acceptable public health levels that can be met by products and materials currently manufactured by our industry. However, the events of September 11, 2001, Hurricane Katrina and the financial crisis that has affected the United States from 2007 to present, has unveiled the need to achieve new high-performance materials that enable designers, developers and owners to produce buildings and infrastructure that resist natural and manmade hazards. There is also the need to create solutions that address safety, durability, energy and environmental concerns such as strength, stiffness and ductility.

A range of new materials has recently been developed that includes important high-performance attributes. These attributes incorporate security, blast protection, resiliency, durability and cost effectiveness. As the rate of development of advanced materials increases, the need for a systematic organization of the properties of these materials becomes necessary. The U.S. Department of Homeland Security (DHS) acknowledges the fact that new requirements call for the development of metrics and benchmarks that will provide a range of verification and validation methods for each high-performance attribute in order to optimize the use of new materials. This new approach is seen as a step toward a new strategy that integrates all major attributes to improve, in a cost effective manner, the rehabilitation and construction of buildings and infrastructure nationwide.

This article describes the structure of the Advanced Material Database and its usefulness to infrastructures stakeholders.

A GENERAL DESCRIPTION

There are numerous web-based material databases that are available on the internet. These databases vary in complexity, applications and objectives. The Advanced Materials Database is also web-based. Its main objective is to enhance the utilization of advanced materials to increase the security and safety of infrastructure at reasonable costs.

In order to achieve such an objective, several unique features were developed for the database. The database will:

1. Enhance the utilization of advanced materials in improving the security and safety of infrastructures;
2. Provide organized descriptions of advanced materials;
3. Provide descriptions of the testing protocols of the materials;
4. Help in establishing interactions between security designs, energy savings and environmental sustainability;
5. Help in utilizing advanced materials in emerging engineering paradigms such as performance-based engineering; and
6. Help manufacturers of newly developed materials apply for U.S. Safety Act approval.

While striving to achieve all of these unique features, the design of the database aims to be simple to use and comprehensive in scope.

Generally speaking, the web-based database has three main components that are closely related. These components are:

1. Front-end (input fields);
2. The database structure; and
3. User queries and search capabilities.

A detailed description of these components follows.

THE FRONT-END

One of the main difficulties in building a database is the technique of entering the information into the system. This is particularly true for a materials database, since it is such a complex issue. The information in a materials database varies greatly from quantitative to qualitative. It also can be deterministic or probabilistic. Sometimes the database user wants to explain some material properties in short notes and in other instances, the user needs to provide much longer text or articles.

In order to accommodate these varied needs, the input fields to the Advanced Materials Database were designed to include many input modes. A *binary* field (yes/no) is provided to describe the utilization of the material in certain situations. For example, you may ask, "Has this material been used for blast hardening?" Or, "Is this material applicable to use in the transportation sector?"

Binary fields are usually coupled with other fields that allow the users to explain their answers in more detail.

A limited-length alpha-numeric *notes* field will be available to users to provide short descriptions or explanations whenever needed. For example, the *notes* can be used to explain a particular binary choice, or to clarify a particular value of a material property. When longer descriptions or essays are needed, the user can upload *files* to specific locations in the database. Files can contain previously published papers, a description of materials, graphics or pictures, tests or a list of citations.

The database recognizes that there are fields that can't be described in a simple numeric fashion. Because of this, a *qualitative* mode of input is also provided. Such a mode is available when the material's properties need to be described qualitatively. In such a situation, a qualitative scale is allowed. The qualitative scale contains six classes:

1. Very High (VH);
2. High (H);
3. Medium (M);
4. Low (L);
5. Very Low (VL); and
6. Not Applicable (NA).

A notes field always accompanies the qualitative choice and it is strongly recommended that the database users explain the basis of their qualitative choice in this field. Examples of a qualitative use include descriptions of the corrosion behavior of a particular material or environmental issues that might relate to a material.

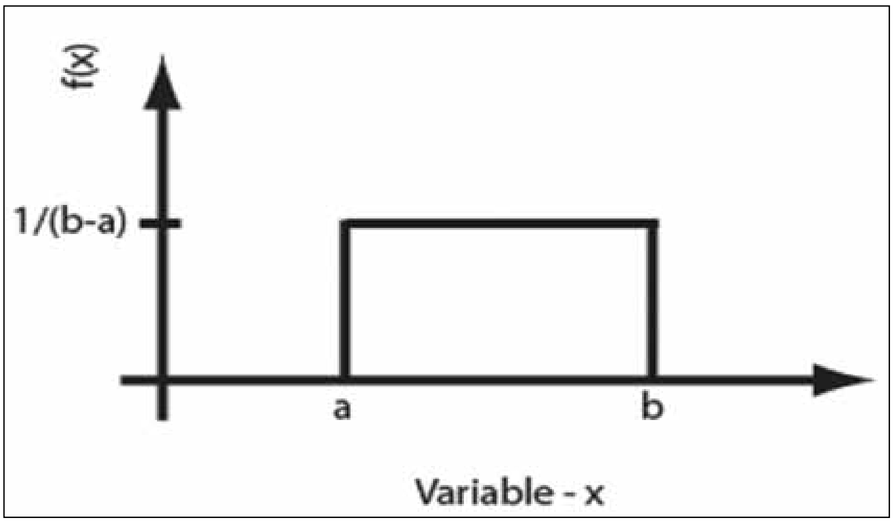

Figure 1. Uniform Probability Distribution of the Material Property. This is used in the database when only the maximum and minimum values of the property are known.

Most material properties are described in the database using *numeric* (qualitative) fields. Examples of such properties include mechanical properties such as ductility or tensile strength, energy-related properties such as R-value, physical properties such as temperature coefficient, or environmental properties such as toxicity.

Each material property can be described numerically in one of several modes. The simplest mode is the single-number entry which would describe the average value of that property. Another mode is a two-numbers range that would provide a range for that property. In such a situation, the internal statistical queries of the database would assume that the probability distribution function of that particular property is uniform (FIGURE 1).

A truncated normal probability distribution can be described for a particulate material property by entering three numbers: upper bound, lower bound and coefficient of variation (FIGURE 2).

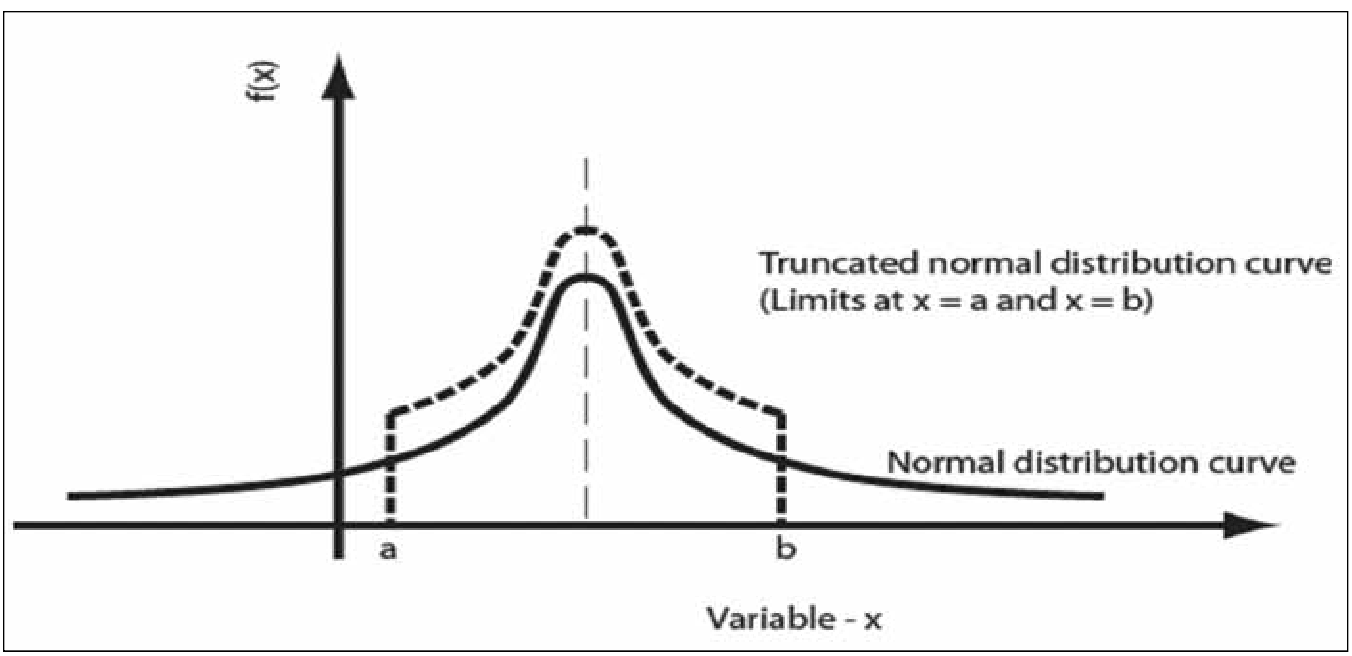

Figure 2. Truncated Normal Probability Distribution of the Material Property. This is used in the database when the maximum, minimum and standard deviation values of the property are known.

There are many material properties, such as viscosity, that are temperature dependent. To accommodate temperature dependency, the users have the option of specifying a temperature-dependency table with up to five temperature instances.

THE STRUCTURE OF THE DATABASE

The structure of the Advanced Materials Database was designed with three principles in mind: *integration*, *scalability* and *decision-making* (FIGURE 3). The integration principle acknowledges that infrastructures are subjected to many demands. One of the most important demands is to ensure the security of the stakeholders. Because of this, the material properties and behavior in regards to bomb blasts is one of the governing factors in designing the database structure.

The economic and efficient utilization of materials necessitates the considerations of other demands too, such as earthquakes, wind and floods (thus the integration principle). As new materials are developed, additional material characteristics, or infrastructure performance demands, might need to be added to the database (thus the scalability principle). Finally, it is desirable to have the database aid the users in an active way by employing some decision-making algorithms within it.

FIGURE 4 shows the basic components of the database. The first component is the attributes component, which contains several performance qualities that are needed from modern infrastructures (including being able to withstand bomb blasts, earthquakes, winds and floods). Other performance attributes can be added in the future, as needed.

Other database components are material descriptions, material characteristics and material testing. Material description components include the potential utilization of the material in infrastructure sectors (18 sectors as delineated by U.S. DHS), material categorization (polymers, metals, ceramics, etc.) and general issues (material names, history, researchers, owners, etc.). A description of the interrelationship of the material with the U.S. Safety Act is a sub-component of the general issue component (FIGURE 5).

Material characteristic components include physical properties (strength, stiffness, ductility, fatigue, etc.), and also include embedded algorithms that would evaluate how the material's properties would meet certain performance demands, such as blast event demands from infrastructures. The material characteristics component also includes energy (for example, potential energy savings) and environmental (for example, potential environmental benefits) material properties and material composition. The testing component contains descriptions of the material testing protocol (destructive, nondestructive, testing standards, etc.), testing results and the manufacturing

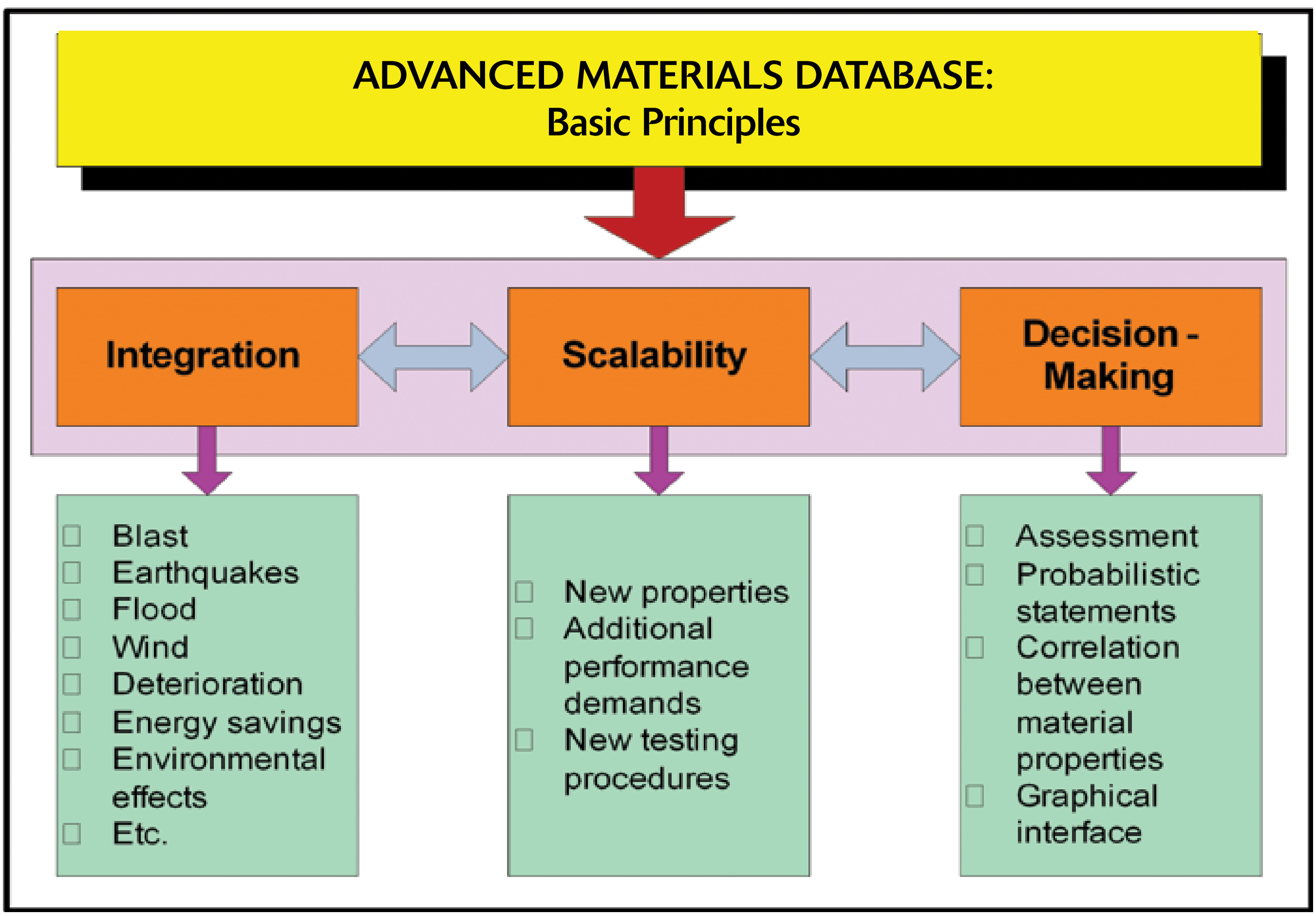

Figure 3. The basic principles of the database.

methods/processes (pultrusion, foundry, QA/QC, etc.) of the material.

DATABASE QUERIES

In order to take advantage of the rich contents of the database, a varied set of user queries can be used, and they can be either alpha-numeric or graphic. Alpha-numeric queries are based on searching the database using filters or search words. Examples of some potential queries are:

1. What are the available materials in the database that have a 90 percent chance that its flexural ductility is greater than 12?
2. List all database materials that have an average tensile strength of 60 ksi (or more), an average R-value of 3.0, and minimal toxicity levels.
3. Show all database materials that can be used for blast design with minimal environmental effects.
4. Show all blast-related materials that have desired optical properties (can be used for energy-efficient glass designs). What are the environmental properties of those materials?

- In addition to the powerful query capability of the database, it is possible to show some query results graphically. For example, for a desired ductility level, how would four specified materials compare? FIGURE 6 shows possible graphical results of such a query. A 2D cross-correlation between material properties can also be shown graphically. For example, for a required ductility and tensile strength, the correlations and ranges of ductility and strength of six materials that are specified by the user can be shown in a graphical form, as in FIGURE 7.

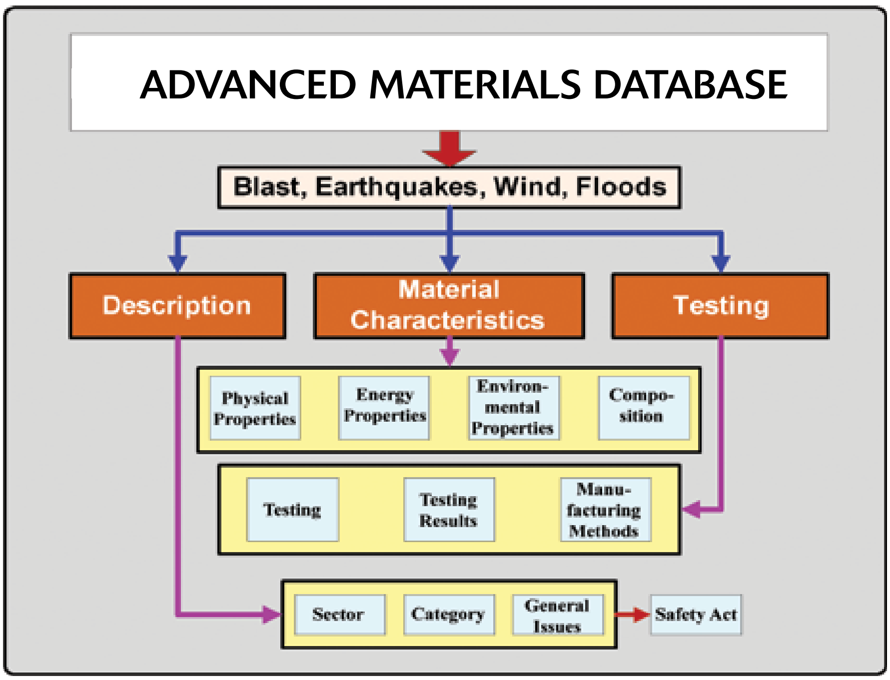

Figure 4. An overview of the Advanced Materials Database.

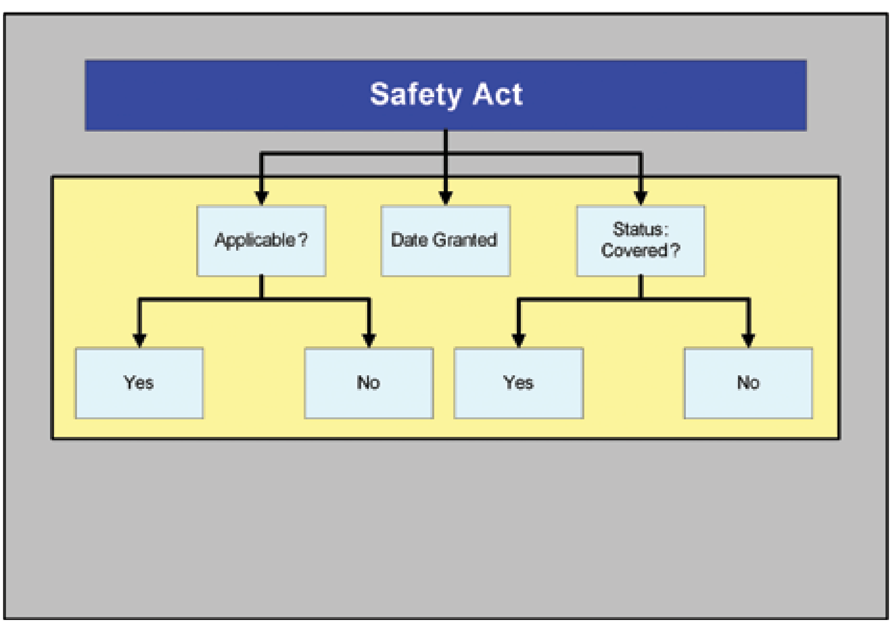

Figure 5. Safety Act considerations in the database.

BENEFITS OF THE DATABASE

The design of the Advanced Materials Database can result in many advantages:

- Enhanced security: by understanding the different capabilities of the materials, an enhanced design that takes advantage of such capabilities is possible.
- Cost savings by using the most suitable material for a given demand.
- Increased multidisciplinary interaction between stakeholders (researchers, manufacturers, owners, engineers and architects) at different stages of the development of materials. Such an increased interaction has the promise of increased performance and security while reducing overall costs.
- By having different demands (performance attributes, such as blast, earthquakes, wind and floods) related together within the organized structure of the database (FIGURE 4), a multihazard design of infrastructures can be performed efficiently. Multihazard designs can improve security, while reducing costs.
- The database includes a comprehensive mix of material properties and performance attributes. This mix can result in the utilization of environmentally friendly and energy-efficient blast mitigation solutions for infrastructures.
- The probabilistic capability of the

database would help the development and utilization of emerging probabilistic-based engineering design paradigms, such as performance-based engineering, risk-based designs and lifecycle analysis of infrastructures.

- The database has a component that specifically addresses the U.S. Safety Act. This will help newly developed materials gain Safety Act approval.
- The included testing and manufacturing component in the database would improve testing accuracy, thus improving the reliability of new materials. This will, in turn, increase confidence and speed the incorporation of such materials in construction of infrastructure.

To summarize, the development of the Advanced Materials Database can result in increased security and efficiency of infrastructures, while reducing overall costs. ■

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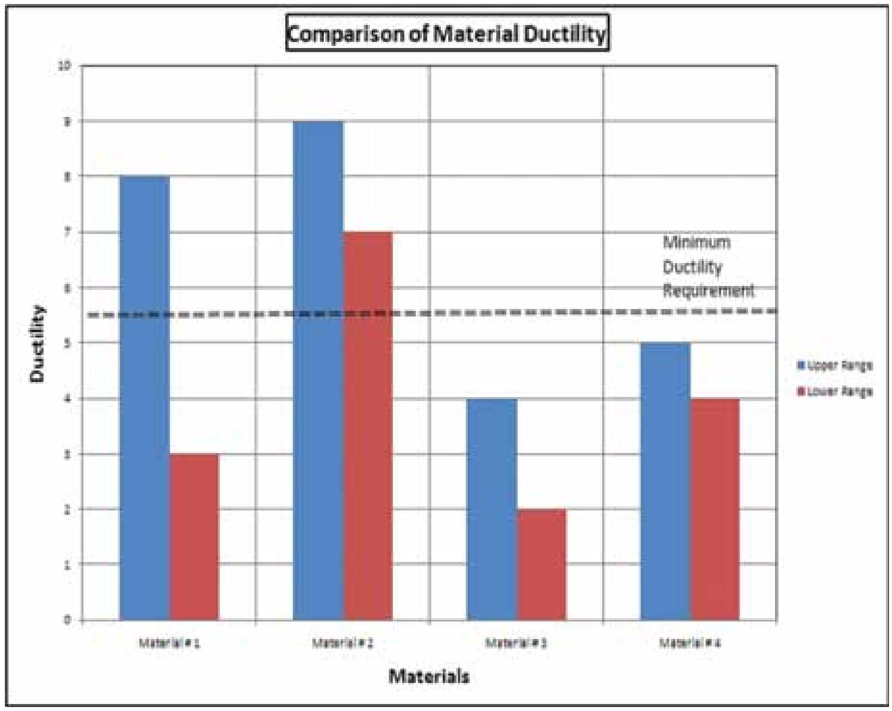

Figure 6. A Decision-Making Graph: Single Component.

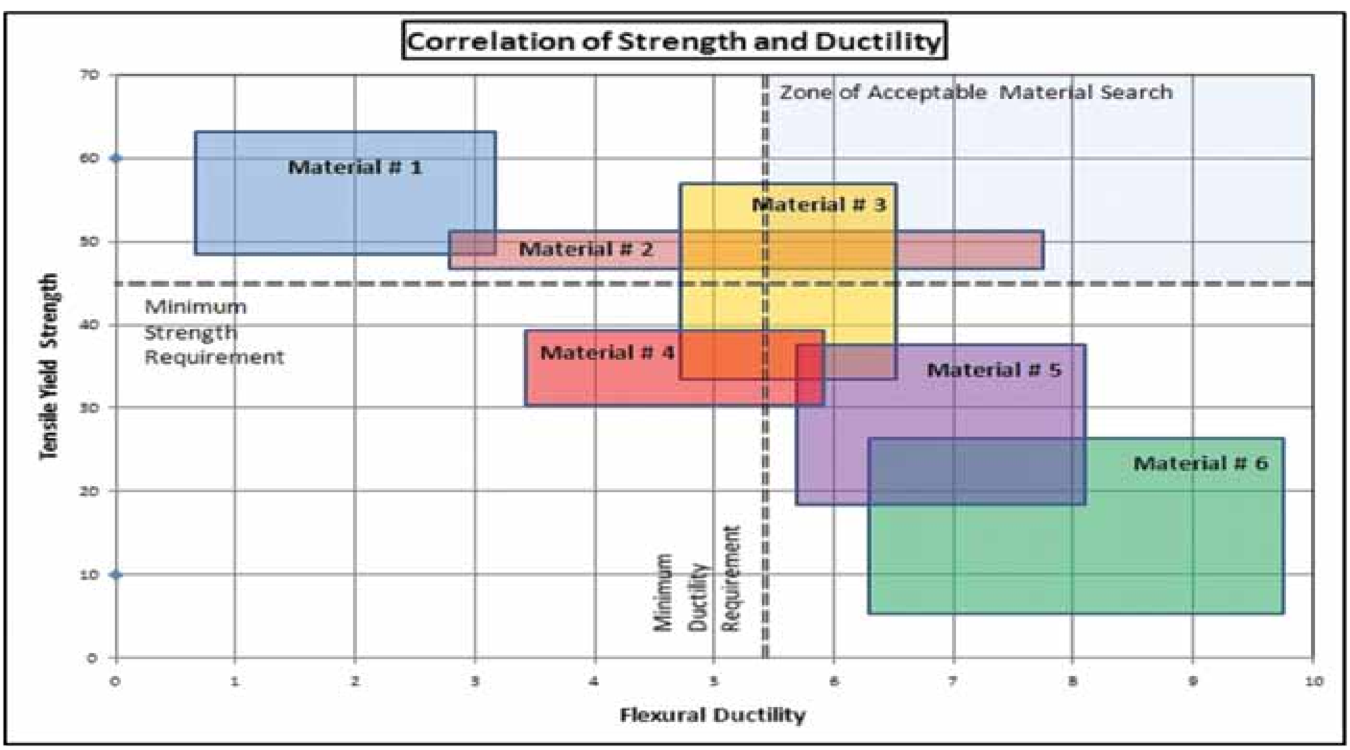

Figure 7. A Decision-Making Graph: The Cross-Correlation of Two Components.