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Novel Adhesives Innovation Through Forward Looking Specifications Requirements and Database Implementation

by Wendy Kosik, Richard Squillacioti, Wayne Ziegler, Jared Gardner, and Robert Jensen

ARL-RP-324 **June 2011**

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14. ABSTRACT

The U.S. Department of Defense is tasked to respond to a wide range of asymmetric threats with speed and efficiency. Historically, the time required for moving new materials and processing technologies from research to application is roughly 40 years. The Department of the Army is actively moving toward a culture of innovation where experimentation and prudent risk taking are not only encouraged but admired.

Advanced materials are the foundation to the performance of complex armor and weapon systems that are often tailored to defeat specific threats. Adhesive failure is detrimental to both structural and ballistic performance. Understanding the adhesive response during a ballistic event is vital for rapid response armor design solutions.

The goals of this research are as follows: (1) use materials informatics to efficiently capture, organize, and explore adhesives structure-property-performance relationships; (2) define adhesive performance specifications for composite integral armor applications; and (3) transform the Army's ability to carry out adhesive engineering, modeling, and simulation research, with a primary focus on high-rate loading. This vision will accelerate delivery of technical capabilities to win current and future fights via materials informatics.

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informatics, database, adhesion, armor, ground vehicle, standards

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NOVEL ADHESIVES INNOVATION THROUGH FORWARD LOOKING SPECIFICATIONS REQUIREMENTS AND DATABASE IMPLEMENTATION

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Objectives

The DoD is tasked to respond to a wide range of asymmetric threats with speed and efficiency. Historically, the time required for moving new materials and processing technologies from research to application is roughly 40 years. The level of complexity and responsibility of modern warfare significantly narrows the range and scope of feasible innovative pursuits.[1] However, the department of the Army is actively moving toward a culture of innovation where experimentation and prudent risk taking are not only encouraged but admired.

Advanced materials are the foundation to the performance of complex armor and weapon systems that are often tailored to defeat specific threats.[2] Adhesive failure is detrimental to both structural and ballistic performance. Understanding the adhesive response during a ballistic event is vital for rapid response armor design solutions.

The goals of this research are as follows. 1) use materials informatics to efficiently capture, organize and explore adhesives structure-property-performance relationships 2) define adhesive performance specifications for Composite Integral Armor (CIA) applications 3) transform the Army's ability to carry out adhesive engineering, modeling and simulation research with a primary focus on high rate loading. This vision will accelerate delivery of technical capabilities to win current and future fights via materials informatics

Materials informatics

Materials informatics (MI) can be described as applying computational methods to processing and interpreting scientific and engineering data. MI can be broken into 3 stages; Data Generation, Data Management, and Discovery.[3] Care needs to be taken to ensure that material data collection, analysis and dissemination has optimized impact for both practitioners and researchers. *Data Generation* must encompass the pedigree and processing history of discrete value parameters, as well as more complex response curves. Capturing and documenting as much materials response information as possible without prejudice will allow for data to be used with current and future accepted analysis schema. (3) *Data Management* should be directed toward reliability, search flexibility, and accessibility. Curators of digital data need to be established to ensure semantic and ontological continuity of the collection.[4] *Discovery* may utilize statistical analysis, physical modeling, data mining (DM), and experimental validation, which is best achieved through an open collaboration between government, industry and academia.

<u>Data generation & management toward adhesive innovation</u>

To effectively manage the vast multidimensional subject of adhesive materials - much like a curator- responsibility begins with the acquisition of the data.[5] MAPTIS-Materials and Processing Technical Information System, is a NASA-wide materials database established for the purpose of recording and disseminating material information.[6] The Army Research Laboratory (ARL) has set up an adhesive database on Materials Selection and Analysis Tool (MSAT) through this DoD-NASA partnership. To preserve data integrity, it is desirable to automate the collection and storage of the raw data in this central, secured system. Both discrete value parameters as well as more complex response curves populate the adhesive database. Augmenting the materials data are other appropriate fields (organization of origin, operator, calibration, environmental conditions) to enhance accountability and confidence. Methodology and taxonomy of fields are closely linked with ASTM identifiers.[7-9]

More than just storing the data, the ability to retrieve relevant decision making information must be part of the value metric. Navigation tools are being explored to allow end users to search from “alternative point of views” the same data. The goal is to *not* be an adhesive expert and still be able to find the desired critical parameters, response curve, or test set up all from the same verified source. We feel strongly that providing multiple scientific and engineering disciplines information from the same source will provide the impetus to move theoretical, model and experimental tests toward agreement/validation. The database will be extensively “hyperlinked” to allow end-users further detail of the data, test conditions or resulting reports.

NASA already successfully manages access, security, and various tiers of authorized users via MAPTIS.[6] MAPTIS provides searchable access to other collaborative networked databases involving environmental, economic and processing information. Data curation requires dedication and longevity. The Army has a strong motivation to ensure data history, security and viability: defense, manufacturing competitiveness (virtual manufacturing), environmental requirements, educational directives,[10] and High Speed Computing (HSC) resource development.[11] The treasure of a large data base is not in the recitation of information stored within. It is in the ability to quarry the known information and discover the intrinsic wealth of information within. [12]

Discovery: data to insight

Inspiration rarely occurs in a conference room during a technical progress meeting. Researchers need time to review, digest and delve deeper into data. MSAT's vast network of searchable databases and handbooks provides an open collaboration platform- enhancing communication, documentation and historical archiving. More importantly, interdisciplinary users can intelligently search the contributing materials communities' knowledge, experiences and expertise. Users will have access to large datasets for investigating physical models, constituent relationships, and processing influences.

Adhesive designs can be intimidating due to the enormous range of materials to be bonded as well as the final performance desired. Armor development is complex and deriving a predictive material model is not trivial. Data Mining (DM) is " the nontrivial process of identifying valid, novel, potentially useful, and ultimately understandable patterns in data"[13] DM assumes that constitutive relations exist within the data and that these relations can be derived from the data rather than the laws of physics.[14] When in 1870 Mendeleev derived a predictive relationship of known elements according to increasing order of atomic weight, grouping similar chemical properties in columns leaving blanks of elements yet to be discovered, he used the DM process.[14]

It is desirable to be able to tailor armor solutions to varying threats, adherent materials of economic/manufacturing interest, and constituents based upon environmental concerns/constraints. For this to occur we need to determine the relationship between the adhesive engineering properties and successful armor response, ultimately, such that the predicted armor success effectively represents observed armor performance. Due to the expected nonlinear response in adhesive systems, Principal Component Analysis (PCA) and Partial Least Squares (PLS) will aid in identifying latent variables.[15-17] DM will allow correlations, trends and groupings to be explored more easily- providing guidance as to which variables dominate the desired armor performance.

The processing-structure-property relationship is of significant interest to the entire computational materials science (CMS) community. The adhesive database need not be limited to engineering properties, but expanded to chemical, electrical and atomic properties. This will allow the database to also be used for data mining focusing on atomistic-scale computation. It is conceivable that as data mining and neural networking techniques advance, microscopic-macroscopic correlations would be found.

Developing a CIA adhesive performance requirements document

Rapid insertion of new technology within the DoD is often restricted due to the lack of information given to vendors about the relevant functional and technological needs.[2] A CIA adhesive performance requirement needs to be developed to give vendors a performance target to shoot for, to allow rapid screening of candidate adhesives, and to identify intellectually stimulating research objectives for academia. Ultimately, one should be able to query the database for what adhesives meet proposed mil performance, and other performance specifications as developed. It is our goal that these performance requirements be based upon accepted published testing standards and encourage exploration of novel innovative adhesive materials.

CIA adhesive selection relies heavily on intuitions and experiment. The number and variety of adhesive materials screened is limited by logistics and finances associated with build-and-shoot experiments. As successful armor performance adhesives are predicted via DM, as well as experimentally validated, robust rapid screening protocols will be refined. Initial screening protocols focus on quasi-static ASTM coupon testing at existing Army operating temperature and humidity requirements. Combined tensile and lap-shear joint strengths point toward a property region needed for armored ground vehicles. The proposed military specification is not intended for a specific end use product- but rather as the performance target of adhesives for consideration by vehicle and armor modelers and designers.[18] It is intended to be forward looking and actively modified.

Providing the infrastructure for a culture of adhesive innovation

Technical innovation is based upon a triad: discovery, vision and application.[19] Discovery is often thought as the most important part of the triad. But, equally important are a high impact application and a vision which are deemed worthy of the significant time and funding commitments needed to provide a return on the investment. The ARL Weapons and Materials Research Directorate is a national scientific and engineering resource in enabling materials and manufacturing technologies, protection technologies, threat-target interactions. WMRD's use of multidisciplinary teams, will keep the adhesive development going without getting fixed in any one of its aspects while simultaneously focusing on technologies matched to our compelling armor needs.

Collaborative efforts in developing and using the database would benefit government, industry, and universities. Industry can refocus DM for environmental, economical or social driven correlations for improved product development. "Companies which use high performance computing find that such tools can generate new insights, cut costs by reducing the number of physical prototypes needed, reduce time to market, and optimize complex functions like supply chains or risk management assessments".[20] Academic study of underlying high rate adhesive response and the physical models at play is encouraged. The adhesive database can provide the integrated computational materials engineering (ICME) and the modeling and simulation community a significant volume of theoretical and experimental data which is needed for data mining, neural network [21] and code development/validation.

Successful exploitation of this adhesive database does not focus on the database itself, but rather on focusing on what it can do. "The central meaning of innovation [thus] relates to renewal. For this renewal to take place it is necessary for people to change the way they make decisions, they must choose to do things differently, make choices outside of their norm."[22]

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