Section1. Introduction, Conclusions, and Recommendations

1.1 Introduction

The availability of materials data is a critical component of Department of Defense (DoD) strategy to maintain world leadership in science and technology in support of its missions for the military, national security, and others, while adhering to current fiscal constraints. As DoD and its contractors design, build, and operate next-generation hardware systems, taking advantage of new and improved materials is an important key to the success of those systems.

The importance of access to high quality scientific and technical (S&T) data has become increasingly apparent in this age of data-intensive science. The ability to generate, store, manage, and reuse large amounts of data has driven new modes of scientific research, including data mining, modeling and simulation, and knowledge discovery. In addition, the globalization of research means that significant S&T data sets generated outside the United States should be available to U.S. researchers. Even though most materials data are generated by "small" science (that is, by individual researchers or small research groups), in aggregate, the entire body of materials research results constitutes a large data set that is increasingly important to state-of-the-art research in the future.

Unfortunately, access to materials property data today is haphazard. There is no single entry point, and data sets that are found using today's search engines are of unknown quality and provenance. In fact, no individual data resource is comprehensive with respect to properties or materials. Therefore, DoD has contracted with Information International Associates, Inc. (IIa) and its subcontractors—R&R Data Services, Freiman Consulting, and the Asian Technology Information Program—to assess current availability, accessibility, and quality of materials property data. This study focuses on ceramic property data as an exemplar of materials data to allow for full understanding of the scope of problems within a manageable case study.

The work comprised several subtasks to provide information, guidance, and insight for DoD's investments and decision-making regarding state-of-the-art access to data and information on ceramic materials and their known properties. The hope is to create one or more self-sustaining, single-access points of entry (data portals) to many or all ceramic data resources that are open to the global community. The initial investment and study objective has been to assess the state of the data in the community (inside and outside the United States) and to develop options for a business plan to determine how to provide state-of-the-art access to ceramic property data. The work consisted of three tasks:

Task 1a. Develop a report on the present-day availability of ceramic property data from open source (digital and print), government-owned, and restricted databases, reports, literature, publications, and unpublished sources, including detailed information of Chinese and Japanese activities in the area of ceramic property data. Detailed results are given in Section 2 and Appendix B (for present-day availability of data) and Section 4 (for activities in China, Japan, and Korea, which was added after the study started as an additional reference point).

Task 1b. Determine options to develop models for web-based access to ceramic property data, as well as potential business models for such access. Detailed results are given in Section 5.

Task 2. Hold a ceramics informatics workshop, to include leaders in the industry and interested potential users that would assess user needs for ceramic property data. Detailed results are given in Section 3 and Appendix A.

From this work, several general conclusions and recommendations are made (Section 1.2), along with DoD-specific conclusions and recommendations (Section 1.3).

1.2 Overall Conclusions and Recommendations

U.S. leadership in materials research is critical for reaching our national defense, economic, and quality of life goals. Innovation and advances in materials today require access to materials data, regardless of where those data are generated or made available. For several decades, the United States was the world's leader in materials data activities through aggressive programs conducted by government agencies, professional societies, private data companies, industrial materials producers, and standards development organizations. However, our review of these activities throughout the world, especially in Asia, reveals that the United States is losing leadership in the area of ceramics (and likely all materials) property data.

To this end, we provide the following conclusions and associated recommendations.

Conclusion #1 – Limited Access to Data

Many ceramics data resources are available, developed and disseminated by diverse organizations. Full utilization of these resources is a challenge because of the following:

- Lack of a single point of access
- Proprietary data whose access is controlled for commercial, national security, or competitive reasons
- No comprehensive directory of resources, their content, or access methods
- No standardized content, especially in terms of the description of ceramic materials and their properties
- Few if any links to tools using the data
- Cost of accessing many of the available sites

Recommendations

- *Recommendations 1A.* The directory of ceramics databases produced by this study should be made freely available to interested parties, who in turn should be encouraged to develop access portals that take advantage of modern web and mobile application technology. As specified in the work statement, an article in the ceramics press will be prepared that will include information for obtaining an electronic copy of the directory.
- *Recommendation 1B.* Federal agencies and private sector organizations should develop new or enhanced existing partnerships to take advantage of new information and web technologies such as the web, data portals, and data science to provide next generation access to materials data resources.

Conclusion #2 – Challenges to U.S. Leadership in Ceramics and Materials Data

- ***The U.S. leadership in ceramics, as well as other materials data in general, is being challenged*** and will require renewed commitment from government agencies, professional organizations, and U.S.-based information companies to maintain the U.S. leadership needed to support advanced materials development, next generation manufacturing, and exploitation of new technologies such as nanotechnology, bio-medical materials, and advanced performance products, including aircraft, automobile, and energy generation.

Recommendations

- *Recommendation 2A.* The United States should reaffirm its leading role in sharing knowledge about materials data and database activities and should also develop an international materials data conference series similar to those sponsored by ASTM International in the 1980s and 1990s. A first step might be to gain full partnership with the Asian Materials Database Symposium Series, perhaps by working to transform it to an Asian-Pacific Materials Database Symposium Series.
- *Recommendation 2B.* U.S. government agencies and professional materials organizations should develop a new *community of interest* to foster development and improvement of ceramics and materials data resources in the United States, including standards, data quality, and knowledge sharing.
- *Recommendation 2C.* Large-scale materials research programs such as the Materials Genome Initiative and the National Nanotechnology Initiative should directly fund materials data activities as an integral part of their research agenda.

Conclusion #3 – Goals for U.S. Leadership

- ***The growing importance of materials data in terms of U.S. leadership in materials research and engineering*** is a consequence resulting from many decades of investment in the information revolution. Whereas 30 years ago the United States had clear international leadership in materials data activities, the rest of the world, especially Asia, is catching and surpassing us. Our national goals in science, engineering, and manufacturing, however, require us to have the greatest possible capability for preserving, evaluating, and disseminating materials data.

Recommendation

- *Recommendation 3A.* Within a year, one or more federal agencies should sponsor an independent, in-depth review of U.S. materials data center activities, with special emphasis on examining the following:
  - The health of existing materials data activities within DoD, the National Institute of Standards and Technology (NIST), the National Science Foundation (NSF), and other agencies, including prospects for long-term financial support and integration within federal materials research programs
  - The status and future prospects of materials data programs supported by U.S. professional societies and independent data organizations and companies
  - Priorities for new materials data activities, especially to support materials advances in the next two decades, such as those required for computational materials science, critical materials substitution, and revolutionary materials advances as generated by technologies, to include nanotechnology, high temperature superconductors, and advanced composites
  - The need for next-generation materials data repositories and data sharing standards