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Issues and Prospects of Materials Databases
— Aiming to Develop a Materials Database to be Used around The World —

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1 Introduction

When we start something new, we research to obtain useful information. Here is a familiar example. Before you go on a trip, you buy a travel guide, obtain tourist information about your destination and find out other details such as the hotels, restaurants and shopping available.

Likewise, when we develop new materials, we must obtain information to determine the combination and composition of materials, as well as a manufacturing process. We may also require data for simulation. When we use new materials for a product, we must obtain material property information or data to ensure the selection of the suitable materials to achieve the intended performance. In this respect, material information and data are essential in providing a base for product development.

The Science and Technology Basic Plan[1] presents a vision for the creation of an intellectual infrastructure to promote science and technology. It states that the government should strategically and systematically improve the intellectual infrastructure, such as research materials, measuring standards, measuring/analyzing/testing/evaluating methods, advanced devices, and related databases. Following the announcement of the Basic Plan, the Intellectual Infrastructure Development Committee, a working group of the Technology and Research Foundation Section that operates under the Council for Science and Technology issued a report[2], entitled "Intellectual Infrastructure Development Plan - Towards the Development of One of the World's Best Infrastructures in 2010" to propose specific measures for database development.

Consolidating material information and data is important for various occasions, and the same problems and issues recur. This is probably because these problems create even more complicated issues that cannot easily be solved or that stem from barriers too difficult to overcome. This paper presents issues concerning the current state of materials databases, suggests measures to overcome these issues, and presents one of the goals of a materials database.

In this paper, the term "materials" does not mean a mere substance, but materials used for product. Data and information are based on materials that are actually used (in engineering), rather than experimental data such as the physical or chemical constants of a pure substance.

2 Issues concerning databases

2-1 Invisible database

A report entitled "Follow-up and Review of the Intellectual Infrastructure Development Plan (Report)"[3] states that 128 materials databases (open to the public) have been created by research institutes and universities, and that the number has increased by 30 since 2002. The number of material property data items has reached approximately 980,000 as it has increased by 180,000 since 2002. These databases are offered by various organizations including the

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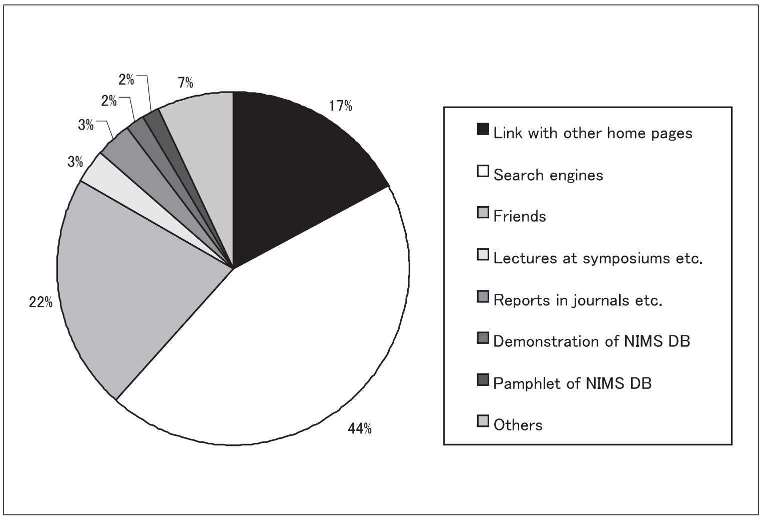
Figure 1 : How domestic registered users came to know about the polymer database*



*One of the NIMS Materials Databases

National Institute of Advanced Industrial Science and Technology (AIST), the National Institute for Materials Science (NIMS) and the Japan Science and Technology Agency (JST). If progress continues at this rate, there will be yearly improvement in the development of materials databases.

The National Institute of Informatics (NII) issues a report every year based on its investigation of the actual conditions of academic information databases. This paper conducted a follow-up investigation of Japanese academic databases using a report issued by NII. The following are findings from the follow-up investigation based on the NII report for 2002[4]. Firstly, 30 samples, which appeared to be from a materials database, were drawn from the databases listed under the category of engineering. It was found that 5 of the 30 databases belonged to NIMS. I searched the remaining 25 databases on the Internet, of which only 12 databases could be located. No information was found about the remaining 13 databases. Surprisingly, they were not accessible from the homepage of the institute or laboratory in question. Most of the 13 databases were created by universities, and it seems that these universities are not aware of people using the database created by their researchers.

Figure 1 shows results of a survey conducted on users of the Polymer Database, which is one of the materials databases offered by the National Institute for Materials Science (NIMS). In this survey, users were asked how they found out about the Polymer Database. Of all domestic users, 44% said that they knew about it via a search engine, 22% from a friend/acquaintance, 17% through a linked page, and 7% through a lecture at symposiums held by an academic society. Of all newly registered users abroad, 72% of them came to know about the database via Internet, and 12% via a linked page. As just described, many users came to know of its existence via a search engine. These days, general-purpose search engines are widely used at home, so it is natural that researchers use a search engine to find information or data at the initial stage of research. The results of the NIMS survey on database users confirmed this trend.

What can we learn from the results of the follow-up investigation based on the data available in the NII report? When we use general-purpose search engines like Yahoo and Google, and enter "material" or "database" for a keyword search, most of the databases listed in the NII report do not appear on the screen. Even though the keyword may not be appropriate, these databases are not user-friendly despite the fact that they are open to the public. In fact, they are not specifically designed to serve outside users. They are only private materials databases used among colleagues, and are not open to the public. Many existing databases have been created by researchers for their own use, and thus are not visible to general users. If a database is to be open to the public, it should be designed to be seen and used by general users. A database has significant meaning only after it is open to the public and widely used.

2-2 Japanese databases struggling for survival

Together, the Japan Aluminum Association and the Japan Research and Development Center for Metals published a report on the development of a non-ferrous metals database, entitled "Study of the State of Intellectual Infrastructure in the Field of Materials"[5], which states the findings of a survey conducted in 1999 to investigate the circumstances surrounding non-ferrous metals and other materials databases. The report provides a list of recommended materials databases. The list consists of 8 databases created in Japan and 9 databases developed overseas. The lineup gives the impression that some of them have been selected in an arbitrary manner because of the personal connections of those who conducted the survey. Five years on, a question has been raised regarding the databases created in Japan. Of the 8 databases, 2 databases suspended operation. NIMS offered 3 databases (including a database taken over from JST), and companies and universities continued operating 3 databases. In the meantime, all of the 9 databases developed overseas remained in good condition.

As indicated in the report issued by the Intellectual Infrastructure Development Committee and as frequently pointed out, many domestic databases do not live long. In Japan, a research budget is allocated for database development, but it is not easy to secure a budget for database maintenance. Two databases that suspended operation make a good example. Considering the large budget required for database maintenance, this is understandable, but we must create ways to maintain a database.

There is another reason that many materials databases do not last long. As already mentioned, a materials database is often developed as part of a research project. A researcher who has created a database tends to see it as his/her own property, which makes it difficult for an organization to interfere with its operation. The design of a database often reflects the individuality of the researcher who created it, making it difficult for another researcher to take over its operation. Given this, an organization must make coordinated efforts to develop a database from the initial stage so that it can be taken over smoothly. It is important to educate researchers so that they are aware of their responsibility to return a database to society because it has been funded with taxpayers' money. Database development largely depends on the ability and efforts of researchers, and this calls for an assessment system that rewards researchers on the basis of their efforts to develop a database.

3 Materials databases in Japan

3-1 NIMS Materials Database

In April 2003, NIMS launched the NIMS Materials Database[6] on the Internet by consolidating the databases from 3 resources: materials databases created and opened to the public when it was known as the National Research Institute for Metals, an electronic form of Structural Materials Data Sheets, and databases that NIMS took over from JST. Currently, the NIMS Materials Database is offered by the Materials Information Technology Station, one of the units of NIMS. NIMS has published creep and fatigue data sheets since 1966. It has been making a coordinated effort to publish these data sheets, and their quality control system fully complies with ISO9001. At NIMS, databases are developed in the same way as the Structural Materials Data Sheets.

As Table 1 shows, the NIMS Materials Database consists of eleven databases. These databases can be categorized into two groups; (i) those based on original test data (e.g. electronic form of the Structural Materials Data Sheets such as the Creep, Fatigue, Corrosion, and Space Use Materials Strength Data Sheets) and (ii) those consisting of data taken from scientific literature and thoroughly examined by specialists for relevance (e.g. Polymer Database, Diffusion Database, Superconducting Materials Database). Creep Data and Fatigue Data are the unique databases in the world that offer highly reliable and professional information. Data in the Polymer Database are taken from scientific literature concerning polymers in accordance with basic principles. For this reason, NIMS Materials Database offers a wide variety of highly professional information. It is useful for materials specialists, but it is difficult for non-professional users to make good use of the data. As a result, engineers of small and medium companies have asked for more detailed explanation.

Figure 2 shows the number of registered users of and the number of visits to the NIMS Materials Database. The number of registered users was about 13,800 as of the end of July 2004 (about 10,600 domestic users and about 3,200 overseas users). Researchers and engineers from companies account for 60 to 70% of the registered users, and about 80% of the registered users for highly professional databases such as the Structural Materials Database and Polymer Database. The NIMS Materials Database is aimed at delivering a "materials database that is commonly used." In this paper, a "materials database that is commonly used" does not mean a "materials database that is easy to use," but a "database with valuable contents that attract users."

Table 1 : Outline of the NIMS Materials Database

Database	Content	Number of Data Items(as of June 2004)
Structural Materials	Creep, Fatigue, Corrosion, Space Use Materials Strength	Creep and Fatigue Data Sheets in PDF files (50 files for Creep Data, 96 files for Fatigue Data), Fact Data
Nuclear Materials	Nuclear change, neutron irradiation	Mechanical properties data, Approximately 15,000
Pressure Vessel Materials	Strength properties of Cr-Mo alloy steels	Strength properties data, Approximately 4,800
Welding	CCT diagram for welding	CCT diagram for welding, 370 steel types
Polymer	Sample property, dictionary	Polymer, Approximately 10,000 Property Point, Approximately 100,000
Basic Crystal Structures	Crystal structure, X-ray diffraction	Crystal structure, Approximately 27,000 X-ray Diffraction, Approximately 27,000
Electronic Structures	Electronic structure, elemental property	Electronic structure, Approximately 160
Diffusion	Diffusion data of metals, alloys and intermetallic compounds	Diffusion coefficient, 3,500
3D Demo System for Ternary Phase Diagrams	Phase diagrams of alloys	5 types
Superconducting Materials	Superconducting properties	Properties of superconducting materials, Approximately 30,000
High Magnetic Field Engineering and Cryogenics	Low-temperature properties	Thermal and superconducting properties, Approximately 10,200

Figure 2 : Number of registered users of and number of visits to the NIMS Materials Database

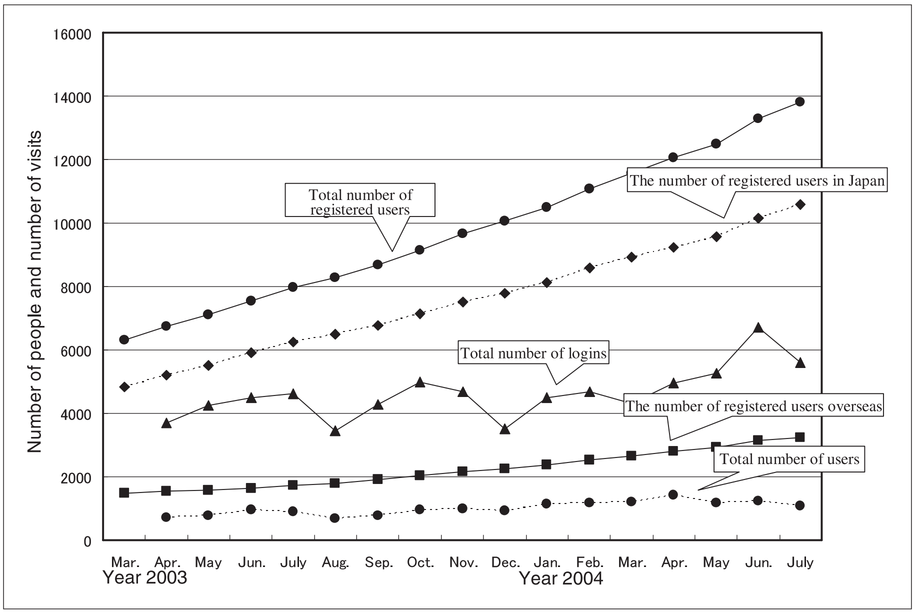
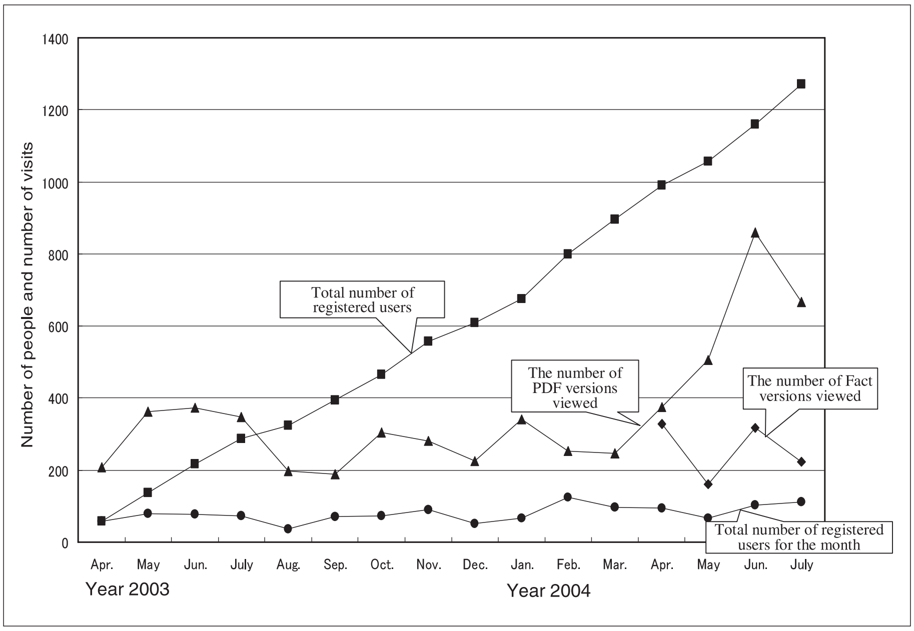


Figure 3 : Number of registered users of and number of visits to the Structural Materials Database*



*One of the NIMS Materials Databases

Figure 3 shows the number of registered users of and the number of visits to the Structural Materials Database. This database is centered on a project to offer structural materials data sheets, which makes it different from other databases. Since its launch in April 2003, the Structural Materials Database has been offering structural materials data sheets in the form of PDF documents. Its Fact version, which adopted a common database design, was launched in April 2004, enabling users to select materials and conditions to design their own products. Although it was expected that the Fact version would attract more users, the PDF version continued to be in greater demand. The PDF version comes as a printed data sheet containing detailed information and data. On the other hand, the Fact version offers major data and avoids complex database structures. Instead, it offers the function of browsing factual data retrieved from the database and describing relationships between different materials using diagrams. Detailed analysis has not yet been conducted. However, this trend suggests that users expect a database to provide detailed information rather than be a function enabling them to present data as a diagram.

There is no point in comparing the number of registered users or databases viewed for different databases because we do not know how institutes interpret these figures. However, a comparison with commercial databases in the US reveals a huge gap between the number of databases viewed in the US and that in Japan. Even a highly professional database like the NIMS Materials Database has fewer users than a general-purpose commercial database in the US.

3-2 Materials database offered by AIST

The National Institute of Advanced Industrial Science and Technology (AIST) developed a research information database (RIO-DB)[7] in 1995 to contribute to technological advancement and to foster industry growth by providing research results and factual data. At its onset in 1996, RIO-DB had 22 databases open to the public with the total number of visits (the number of databases viewed) being 310,000. In 2003, the number of databases open to the public increased to 77, with the total number of visits exceeding 30 million. Table 2 shows RIO-DB databases open to the public by category[8]. To select areas suitable for databases and meet the strong demands of academic societies and the industrial community, AIST places particular emphasis on three types of database: a large-scale database that takes a long time to develop, a geology-related database, and a unique database that can only be offered by AIST.

Table 3 shows outlines of materials databases

Table 2 : Number of databases for the AIST Research Information Database RIO-DB by category

Category	Number of databases	Number of archived databases (stored without updates)
Life Science	8	0
Information Communication	5	0
Nanotechnology, Material, Manufacturing	16	2
Environment, Energy	19	6
Social Infrastructure (Geology, Marine)	16	1
Social Infrastructure (Standard)	10	2
Other (Publicity)	3	2
Total	77	13

Table 3 : Outlines of materials database in the AIST Research Information Database RIO-DB

Database	Content
Materials-LCA Data Base for Ecomaterials Design	Research and development of composite materials based on LCA
Optical Properties of Ceramics and Ceramics Thin Films	Optical properties such as transmittance, reflectance, and emissibility of ceramics and ceramic thin films
Superconductivity Papers Database	This database mostly covers articles on superconductivity after the advent (1987) of the high-temperature superconductor. It contains high-temperature superconductors (49,852 entries), C60-related (3,233 entries), organic conductors (2,377 entries), non-oxide superconductors including conventional superconductors (7,973 entries), oxide conductors (3,272 entries), theory (6,556 entries)
Database for Metallic Material Design	This database covers the development of implant materials at AIST
Manufacturing Database	Data on welding, electronic grinding and cutting
Ceramic-Color Database	Ceramic glaze data, Number of data: 1488
Database for Assessments of Metals in Aggressive Environments	Mechanical property data for metallic materials used in harsh environments such as high-pressure hydrogen gas, high temperatures and ultracold temperatures (e.g. tensile properties, fatigue properties, fatigue crack growth, fracture toughness/elastic plastic fracture toughness, creep properties and fracture surfaces of metallic materials)
Electronic System Integration Technology Database	Technical papers and data related to next-generation packaging technology (3D packaging, optical packaging), Total number of data items: Approximately 7,700
Light-Metal Composite Material Database	Superplastic deformation of aluminum composite materials, Materials properties (mechanical properties, thermal properties, abrasion resistance)
Database for DDS Nano-Materials Applying Complex Carbohydrate Ligands	DDS nano-materials data that can be applied to drug delivery systems (e.g. molecule design/synthetic method, disposition of tumor-bearing mice, model for sugar chain molecular structure, assessment of molecular recognition/function)
Ceramic Materials in Japan	Data can be searched by category, such as type/category, area, chemical composition and other properties, and supplier
Underwater Technology Database	This database consists of underwater welding, underwater cutting and ultrasonic databases
Database of Plastic Thermophysical Properties	Specific heat for every 10 degrees centigrade, thermophysical properties such as required enthalpy in the solid, fusion, thermal cracking or vaporization area
Network Database System for Thermophysical Property Data	Thermophysical property data such as thermal conductivity, thermal diffusion rate, specific heat capacity, coefficient of thermal expansion, and radiant heat. This database system allows access to the databases of independent research institutes on the Internet. Number of data items: 765
Integrated Spectral Data Base System for Organic Compounds	This is an integrated spectral database system for organic compounds (SDBS), which includes 6 different types of spectrum under a directory database of the compounds. (Compound dictionary: Approximately 32,200 compounds, Mass spectrum: Approximately 22,600, 1H NMR spectrum: Approximately 14,000, 13C NMR spectrum: Approximately 12,300, Infrared spectrum: Approximately 49,200, Raman spectrum: Approximately 3,500, ESR spectrum: Approximately 2,000)
Raman Spectra Database of Minerals and Inorganic Materials	This is a spectra database of minerals and inorganic materials based on research and development data on ceramics. (Minerals: 485, Inorganic compounds: 396, Reference literature: 100)

offered by AIST. Some of them are already archived because no-one oversees or updates them. On the other hand, coordinated effort and time are devoted to large-scale databases. For example, the Integrated Spectral Data Base System for Organic Compounds[9] is a large-scale database that attracts many users, accounting for slightly more than 80% of the total number of visits to RIO-DB. This organic compounds database includes 6 different types of spectrum. Its development began in the 1970s. A general-purpose host computer was used to accumulate data from the 18 years of its history. Today, a personal computer is used to add and update the data in RIO-DB.

AIST is devoting time and coordinated effort to developing a database based on its years of research experience. They have a clear vision of the database to be developed, and they are developing it based on an understanding of user needs. This is only possible at public institutes like NIMS and AIST that can afford the continued effort. If Japan intends to develop and establish a unique intellectual infrastructure around the world, public research institutes must play a central role in creating a clear vision for databases to be developed and formulating strategies to maintain them.

3-3 Other materials databases

In Japan, non-public organizations also open their databases to the public. In 1991, the first edition of the INTERGLAD International Glass Database[10] was launched in the form of CD-ROM. The New Glass Fiber Forum, the development body of INTERGLAD, was established in 1985 by a number of leading companies in glass-related fields to encourage businesses specializing in fiber optics or high-tech, new glass industries to promote the collection and provision of information and international exchange for technological development. The Internet edition was launched later. INTERGLAD International Glass Database Ver.5 was also launched with the support of the Measurement and Intellectual Infrastructure Division, the Ministry of Economy, Trade and Industry. It has been reported that there were nearly 1,000 users at home and abroad.

The Society of Materials Science, Japan, has various databases that cover structural materials properties, and the Japanese Fatigue Bibliographic Database is a representative example. The concept of this database dates back to the 1970s, and it was published in 1982 and 1992. Consisting of a wide variety of metallic materials fatigue strength data collected in Japan, it is available as a book and a computer-readable database[11]. It covers a range of materials including steel materials and non-ferrous metals, but consists only of data collected before 1991. The data has not been updated since then.

Meanwhile, industry associations published a materials catalogue featuring data on aluminum, magnesium, titan or other materials[12]. However, these catalogues are small in scale. There are also a small number of databases offered by companies for a fee (e.g. the electronic version of the “Kikai Sekkei (Machine Design)” handbook [13]).

Except for the INTERGLAD International Glass Database, there are only a few materials databases which are offered by non-public research institutes and are truly original on a worldwide scale.

4 Materials databases around the world

4-1 Private sector databases with a large number of users

When we enter “material” as a search keyword to search for information via a general-purpose search engine, one database always appears at the top of the screen: MatWeb[14]. It is offered by a US company called Automation Creations established in 1996. The company offers database applications and business software solutions for governments and companies, and MatWeb is one of their business operations. Through e-mail exchange, I realized how interested they are in database architecture with growth potential. They appeared to be unenthusiastic about improving existing materials databases. However, they are enthusiastic about developing and improving materials databases.

MatWeb is a materials property database containing more than 40,000 entries for more than 400 material properties, and is periodically updated. About 85% of the data is supplied directly from materials manufacturers. Some data and information are taken from scientific literature or handbooks, but most data are the data of materials products from a catalogue. Automation Creations does not perform laboratory experiments to offer data through MatWeb.

Most property information is on plastics, metals, ceramics and fibers, but there are some data on fluxing materials, lubricant agents and liquids. MatWeb offers data for free, but advanced features such as associated tools are only available to registered users for a fee. MatWeb has a large number of users, the average number of users per day being 10,000, and the average number of newly registered users per week being 14,000. It consists of data taken from catalogues published by materials-related companies; thus, there is no guarantee of the accuracy of the data. It offers data on usual materials only.

Nonetheless, MatWeb is very well known throughout the world, and many organizations provide a link to MatWeb. It could make a good model for Japan as it provides a foundation for consolidating materials databases. If we try to compete with MatWeb, we must deliver original features such as functions, quality and reliability that are not offered by MatWeb. However, we must be aware that we could be defeated if we lose in terms of the number of visits to the database.

4-2 Characteristics of materials databases around the world

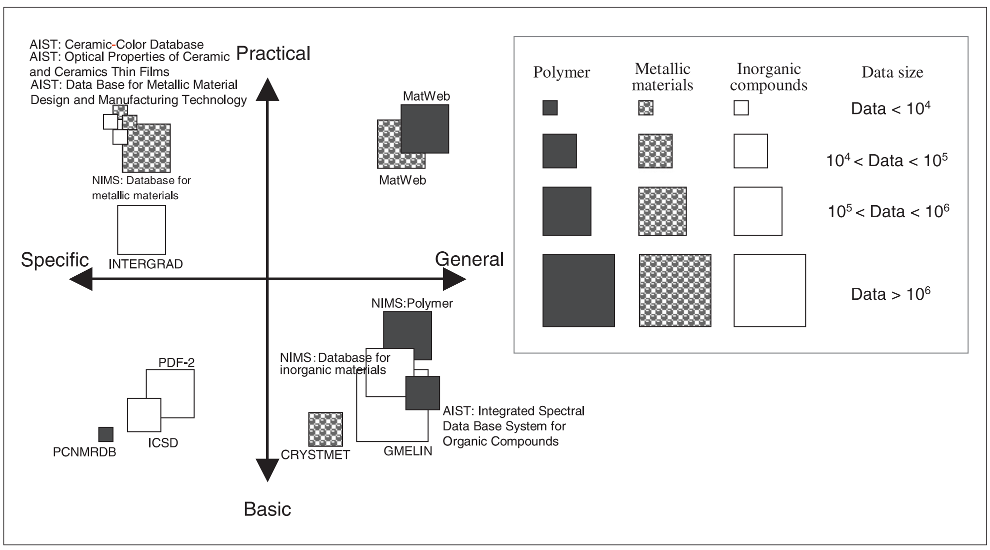
Figure 4 is based on the diagram[15] by Nagasaka et al. It shows the characteristics of materials databases by scale, diversity (whether properties are specific or general) and applicability of data (whether properties are basic or practical).

Japanese databases can be categorized into two groups; databases that focus on specific fields for practical use, and others that cover general fields to provide basic data. The databases tend to be relatively small. On the other hand, European databases such as BEILSTEIN (an organic compound database) and GLEMIN (an inorganic compound database) have data and information collected over nearly 200 years. European databases tend to focus on basic properties.

Based on the above-mentioned conditions, databases can be categorized into roughly three groups: (i) those that have a tradition and contains the basic property data of materials and substances collected over years, (ii) those that have professional information for a specific field and are thus truly original on a worldwide scale, and (iii) large-scale databases that contain information taken from catalogues.

The three categories of materials database show the potential direction of Japan. Because Japan has a short history of science and technology and is behind its overseas counterparts in terms

Figure 4 : Scale and objective of materials database



Source: Prepared by the author based on the diagram drawn by Nagasaka et al.[15]

of the quantity of basic data and information, it is difficult to compete with large-scale European databases of the first category. It is also a challenge to establish a distinct business model and create a large-scale commercial database as described in the third category because success depends on how innovative the idea is. It is difficult, but not a hopeless task, to create such a database. However, this is not what a public research institute ought to do. This leaves one possibility; Japan can only aim to create a database that offers highly professional information and that cannot be rivaled by any other organization.

5 Ideal contents for materials databases that promote manufacturing

5-1 Materials databases that promote manufacturing

Takahiro Fujimoto, a professor at the University of Tokyo, says that the Japanese manufacturing industry is good at developing technologies based on the ideas of the shop floor. He stresses that it is necessary to continue strengthening the institutional capacity and develop architecture (design philosophy) based on this premise[16].

The figures specified by the standards (data found in a catalogue) are not sufficient to develop a product with the most suitable materials. Product development requires a database that contains detailed materials information. As already mentioned, public research institutes such as NIMS and AIST have highly professional databases with a substantial amount of data to meet the needs of a specific field. These databases certainly support the development of manufacturing technologies in Japan.

The following examples show that a materials database must consist of detailed information obtained from research or firsthand experience instead of figures specified by the standards. To create a materials database with detailed information, materials experts must lead efforts to design and build databases, with information technology experts providing technical support. Meanwhile, it is important that a database like MatWeb, which allows users to combine data taken from catalogues, is easy to use. It may well be that information technology experts will lead development efforts in developing a database similar to MatWeb.

5-2 Example of information obtained from an accident

In November 1999, the launch of the H-II Launch Vehicle No.8 from Tanegashima Island failed because of engine malfunction. To investigate the cause of the failure, the engine parts were recovered from the bottom of the Pacific Ocean using cutting-edge technologies. The investigation revealed that the engine stopped when a part of the inducer blade attached to the turbo pump, which pumps liquid hydrogen into the engine, fell off due to metal fatigue. The breakdown of the metal originated on the surface of the inducer blade where there was a tiny scar caused during metal processing. It was found that the fatigue strength of the materials used for the inducer blade was different from that specified in the design, and this became a major issue. The inducer was made from domestically produced titanium alloy. However, NASA’s data on the same type of material was used for the inducer design because data on the material in question was not available in Japan. The grain size of domestically produced titanium materials was larger than that of the titanium materials which NASA used for its experiment. Fatigue strength depends on grain size. The larger the grain size, the lower the fatigue strength. The inducer did not have sufficient strength because it was produced according to design values set by NASA. Since this incident, the importance of obtaining space-related materials property data at home has been recognized. It was decided that NIMS will develop Space Use Materials Strength Data Sheets with the cooperation of the Japan Aerospace Exploration Agency (JAXA). As this example shows, materials do not depend on the elements of the basic components alone. Materials properties data are not necessarily applicable even if the material in question has the same standard name. If you accept the name at face value and use that data in design, unexpected accidents may occur. To use materials safely, we must carefully examine information and knowledge such as the manufacturing conditions and microstructure of the metal.

5-3 Examples of information obtained from materials development and the manufacturing process

(1) Example of auto sheet steel

Japanese sheet steel manufacturers have the technology to produce excellent auto sheet steels. Auto body sheet processing requires materials that change shape homogeneously because these materials do not crack, and they deliver an even thickness when they are formed in suitable dies. The production of such materials requires information sharing and close cooperation among steel engineers, die press engineers and auto body designers. In Japan, engineers from steel manufacturers and auto manufacturers have worked together to develop high-performance auto sheet steels[17]. Because we have to reduce the environmental burden of auto steels, there is a growing demand for the high-strength steel materials required for lighter vehicles and steel materials that are easy to recycle. Materials engineers, auto design engineers and auto manufacturing engineers are expected to work together to develop materials and processing technologies. As just described, it is necessary to develop a database that covers not only information about materials but also the information required for machine design, if materials development and machine design are promoted for products development in tandem.

(2)Example of heat-resistant steel for boilers

Heat-resistant steels used for boilers in thermal power plants must withstand high pressure and high temperature. This means that they must have high creep strength. Boiler design is based on the allowable stress determined by creep strength that ensures 100,000 hours of operation, thereby requiring an experiment to obtain creep rupture strength for 100,000 hours. Currently, such an experiment is being conducted by NIMS and some European research institutes only, because it requires funds, human resources and relevant facilities. Creep strength is sensitive to the microstructure of the metal and is influenced by a very small amount of minor chemical elements. For example, stainless steel properties vary depending on the quantity of boron contained, although there is no standard that specifies the quantity of boron in stainless steels. There is a significant difference between stainless steels containing a few ppm of boron and those containing more than a dozen ppm of boron[18]. Stainless steels with more than a dozen ppm of boron have high creep strength but are brittle, and thus are unsuitable for practical use. A few ppm of boron is added to improve strength and to give appropriate ductility to stainless steels for practical use. Such information, which cannot be found in a catalogue, is indispensable for professionals.

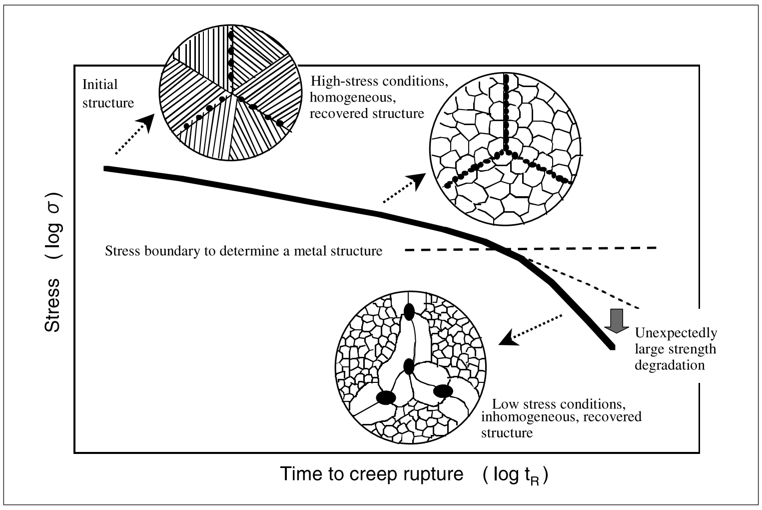
(3) Example of heat treatment simulation

Steel microstructure changes due to temperature and deformation processing, which affects its strength. This is how Japanese swords are strengthened and given a subtle difference in properties. Knowledge and data concerning the mechanics of materials and metal materials science are required to simulate this phenomenon. The development of a database that enables steel heat treatment simulation was conducted by the Society of Materials Science, Japan, under the initiative of Tatsuo Inoue, a professor at Kyoto University. The stress-strain curve was obtained and accumulated for steels that show a significant difference depending on temperature and composition change[19]. This example shows that a strong leadership and cooperative framework are required for the development of a database that features a large amount of diverse data.

5-4 Information obtained from research

Figure 5 shows the creep strength of high-chrome steel. High-chrome steel was developed as a structural material for future fast breeder reactors in the US during the 1980s. It was then diverted to thermal power plants, but efforts continue to deliver high-chrome steel which withstands higher temperatures. Japan developed high-chrome steel with increased strength based on this material. When exposed to high temperatures, the microstructure of the metal changes, leading to a change in strength.

Figure 5 : Stress dependency and effects on creep strength by the microstructure of heat resistant steel during high-temperature creep[19]



This also applies to high-strength heat-resistant steel because its microstructure changes and strength deteriorates over time. Figure 5 shows that recovery is observed in all parts of a material when there is high stress (when creep life is short), but recovery takes place in areas close to the grain boundary only when there is low stress (when creep life is long)[20]. This presents a problem; when a creep test is conducted under high-stress conditions, recovery takes place in all parts of the material. If creep life over time is extrapolated and strength is estimated using test data, the obtained strength will be higher than the actual strength of high-strength heat-resistant steel. If a plant is designed based on the obtained strength, creep rupture is imminent.

6 To build a partnership on a worldwide scale for materials databases

Databases are expected to organize accumulated knowledge and information to help researchers and engineers. They must also provide information to help people locate the source of information. Many materials databases feature highly professional information, but the scale and the quantity of data are relatively small. In addition, materials databases must cover many measurement items, which makes it impossible for any single organization to develop a database that contains data on all of these measurement items.

There is another aspect to a database. Because they are the culmination of research, researchers are especially attached to them. Databases lack compatibility because their creators often use different forms. Despite efforts towards establishing international standards for databases, there has not been much progress. This may be a problem in making effective use of existing databases. The people involved in the existing databases may be reluctant to cooperate if the consolidation of database formats is pushed forward in a high-handed manner.

Professor Ashby of Cambridge University in the UK is a famous materials researcher and author of course books on materials selection for product design, based on a concept developed over years. He has developed electronic materials for teaching materials selection at Cambridge University, created a materials database, and built a materials database network that connects the world's most famous materials databases. He claims that the standardization of database formats or the integration of databases does not matter, and that researchers and engineers only want to know the location of the data and information that they require. He says that they can collect, organize and use data and information once they know their locations. Based on this belief, he has developed a search engine called the Material Data Network by collaborating with Granta Design[21], a venture business originating from Cambridge University.

Table 4 shows a list of databases included in the Material Data Network and database providers (research institute and company).

The Material Data Network consists of various databases provided by the world's leading institutes such as the American Society for Metals (ASM International), Automation Creations that provides MatWeb, the National Physical Laboratory (NPL), The Welding Institute (TWI) and the National Institute for Materials Science (NIMS). This network system functions as a tool to locate data and information and a search engine for professional materials information. Users visit the site based on search results, register for the database and obtain information on their own.

Table 5 shows the amount of information that can be obtained from the Material Data Network. The data obtained from any database that comprises the Material Data Network is one-sided because each database specializes in certain

Table 4 : Outlines of databases Linked to the Material Data Network

Database	Provider		Outline
	Organization	Country	
ASM Handbook	ASM International/Granta Design Ltd.	US/UK	Online metal materials handbook
ASM Alloy Center	ASM International/Granta Design Ltd.	US/UK	Metal alloy properties
ASM Micrograph Center	ASM International/Granta Design Ltd.	US/UK	Collection of micrograph images of metals
IDES Resin Source	IDES Inc.	US	Data on US (ASTM class) plastics provided by resin suppliers
MatWeb	Automation Creations, Inc.	US	Data on metals, polymers, ceramics and other composite materials provided by suppliers
MetalsUniverse. com	National Metals Technology Centre	UK	Properties of materials that meet the standards such as steels, metal-based composite materials and non-ferrous metal alloys, and environmental burden data
MIL-HDBK-5H	Granta Design Ltd.	UK	Property data on aircraft materials
NIMS Materials Database	National Institute for Materials Science	Japan	8 kinds of database in NIMS Materials Database
NPL MIDS	National Physical Laboratory	UK	Material and measurement information
SteelSpec II	UK Steel	UK	Steel data provided by suppliers
TWI JoinIT	The Welding Institute	UK	Welding technology information

Table 5 : Number of data items per database linked to the Material Data Network

Database	Ceramic	Composite	Fibres & Particulates		Form	Metal	Natural	Polymer	Total
			Fibres	Particulates					
ASM Handbook	1629	1909	16	136	263	7816	1063	1010	13842
ASM Alloy Center	1676	449	1	32	13	7685	232	237	10325
ASM Micrograph Center	3	1670	None	1	None	972	36	None	2682
IDES Resin Source	4	678	16	None	33	9	481	13849	15070
MatWeb	2780	834	31	5	254	9990	532	29443	43869
MetalsUniverse.com	2	63	11	None	11	215	3	6	311
MIL-HDBK-5H	20	107	56	None	133	322	6	672	1316
NIMS Materials Database	16563	None	None	None	None	12029	2	10973	39567
NPL MIDS	263	153	31	1	11	351	147	1900	2857
Steel Spec II	None	1	None	None	None	5	4	1	11
TWI Join IT	450	448	171	42	63	500	268	433	2375
Total	23390	6312	333	217	781	39864	2774	58524	132225

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areas. However, these databases make up for each other's deficiencies and allow users to locate data and information that cannot be obtained from a single database. With this network, users can use approximately 140,000 pieces of data.

It is important to remember that the quality of a database cannot be judged from the amount of data. A large collection of data does not provide valuable analysis results if the data quality is not consistent. Rather, a collection of data of various quality increases the data uncertainty, which may lead to negative results or mislead.

7 Requirements for the increased availability of a materials database

This section offers suggestions regarding requirements for a materials database to be developed by materials researchers, based on the above discussion and considering that it is necessary to increase the availability of a materials database and to expand the areas in which a materials database can be utilized.

(1) Developing a materials database that can be used

In Japan, technologies are developed to meet the needs of the shop floor. If we are to continue developing technologies in the same way and lead the world's manufacturing scene, we must develop a materials database suitable for this style of technology development. To develop such a materials database, we should reflect the needs of potential users and exclude the personal feelings of individual researchers. It is necessary to establish a system that enables an organization, instead of an individual researcher, to address database issues. Establishing such a system should be led by public research institutes.

It is also important to develop a "visible database" that enables users to find out about its existence via a general-purpose search engine.

(2) Coordinating database development and software development for effective database use

A database with a simulation facility enables materials property estimation. It is, therefore, essential to coordinate database development with software development that aims to deliver software that enables the more effective use of a database. Software development efforts should be led by database users because different users use data differently.

(3) Seeking partnerships to establish an international data network

A materials database, especially featuring highly professional information, often covers only limited areas. Therefore, it is necessary to combine several materials databases to meet the needs of users. However, each database has a different background and is based on different ideas, which calls for a network system that can accommodate such differences among databases. One possible solution is to establish a system on a worldwide scale similar to the Material Data Network, which enables users to locate the data and information that they require.

(4) Introducing databases in the field of education

In Japan, efforts to promote E-education have just begun as software development has started. As already described, Professor Ashby at Cambridge University took a long time to write course books on materials selection on his own. These course books are truly original and they all initially present an example and a case study. They are designed to help students gain basic knowledge as they analyze each example. Students require certain data and information to analyze an example, so they access a database to obtain the data and information that they require. In this way, the university students have an experience similar to that of materials engineers on the shop floor. If we are to provide the same kind of education, we must first develop educational materials. It is also necessary to develop software for students.

(5) Using databases on the shop floor

Today, materials and products move across borders. This trend is expected to accelerate in the future, and to catch up, it is necessary to develop a business-oriented database that enhances convenience and assistance for the purchase and use of materials around the world. Such a database must offer data and information to be used not only in the technology field but also in various business fields around the world. It must also be based on the common knowledge of those engaged in these fields.

8 Conclusion

Critics often say that databases cost a lot of money but do not pay for the investment. However, the systematic accumulation of data and information provides a basis for the science and technology indispensable for socioeconomic activities and untroubled living conditions. This paper examines the situation regarding databases and discusses what is to be done to develop a database that can be widely used. This paper focuses on user-friendliness in database development from the standpoint that databases have true value only if they are used. Thus, it points out problems in database development, presents ideas to attract more users, and recommends measures to develop a desirable materials database.

The following are the points raised in this paper that require special attention.

- Japan's strength in technology development lies in shop-floor technology. A materials database must be designed to meet the needs of shop-floor technology. Furthermore, it must also meet the needs of users, and be established as a truly original database around the world. It is also important that users can find it easily. Japan should invest funds and human resources to develop a materials database that meets the above needs and to show its strength to the world.
- Each materials database specializes in a certain area. If several databases are combined, they can meet more diverse user needs. The development of a worldwide materials database network provides a key to addressing this issue. However, it is unwise to consolidate existing databases in a high-handed manner. What matters most for professional users is the location of information. Japan should aim to develop a worldwide materials database network system that enables users to locate information. All of us must work to develop a truly original materials database to accomplish this goal.

The following are the points that require attention in developing and improving a database.

- It is necessary to introduce a database in the classroom to give students the firsthand experience of engineers on the shop floor. For this purpose, it is necessary to develop educational materials that reflect the reality of the shop floor, and create a system to support the development of educational materials that incorporate a materials database.
- Once developed, a materials database must be maintained and improved. It is essential to secure a budget for the maintenance of the database, in addition to the budget for its research and development.

To conclude, materials databases that provide mere figures are not sufficient. They have true value only if they provide information about materials. Materials researchers and engineers must lead efforts to develop a materials database that offers highly professional materials information. Their motivation and effort are essential for the creation of a truly original materials database. We expect to see such materials databases as valuable national assets and establish mechanisms to maintain and improve them on a long-term basis.

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