PROJECT COMPLETION REPORT

Setting up of Indian Materials Database for Scientists, Engineers and Industries

Implemented by

Indira Gandhi Centre for Atomic Research (IGCAR)
Department of Atomic Energy (DAE)

Study Sponsored by

National Science and Technology Management Information System (NSTMIS)
Department of Science & Technology (DST)

Principal Investigator : Smt. S. Rajeswari
Co-investigator : Dr. V.S. Srinivasan (Metallurgist)
Co-investigator : Shri V. Sivasankar

(April-2020)

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Principal Investigator: Smt. S. Rajeswari, SO/H
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Study Sponsored by

National Science and Technology Management Information System (NSTMIS) Department of Science & Technology Government of India

(April-2020)

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About NSTMIS:
The National Science and Technology Management Information System (NSTMIS), a division of Department of Science and Technology (DST) has been entrusted with the task of building the information base on a continuous basis on resources devoted to scientific and technological activities for policy planning in the country.

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Disclaimer:
Every care has been taken to provide the authenticated information. However, the onus of authenticity of data rests with the PIs of the project.

Preface

The materials data on physical, mechanical and corrosion behaviour have been generated in various national laboratories and academic institutions in India. Today many institutions are doing advanced research in the areas of materials in order to get insights on structure-property correlations, development of new materials, high-temperature component design, life prediction, and remaining life assessment to suit the energy, chemical, and space sectors. But there is no centralized repository to hold the research output data on the structural materials in India.

IGCAR has expertise in the field of Metallurgy and Materials. Also, IGCAR is collaborating with many high-end research institutes working on Metallurgy and materials in India. The availability of experts in IGCAR in every field of Metallurgy has made the selection of data to include in the database possible. Further, experts have vetted the database thoroughly, which has made the Materials database of India successful.

The information technology experts in IGCAR have made a very novel database model for hosting the present data as well as accommodating the future data. Further cognizance and strict adherence to web application security have played rich dividends.

All the above expertise of IGCAR has led to a great project towards collating and sharing the materials research data of India through a project entitled "Setting up of Indian Material Database for Scientists, Engineers, and Industries." CHORD division of the National Science and Technology Management Information System (NSTMIS) of the Department of Science and Technology (DST) has funded this project.

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Acknowledgments

The Project Team for "Setting up of Indian Material Database for Scientists, Engineers, and Industries," from Indira Gandhi Centre for Atomic Research (IGCAR), would like to thank the CHORD Division, National Science and Technology Management Information System (NSTMIS) of Department of Science and Technology (DST), Government of India for their support and encouragement to carry out this project. The project team would like to acknowledge the infrastructure and administrative support provided by IGCAR. The Team would like to thank Smt Suja Ramachandran (Computer Division, IGCAR), Smt A. Yamini and Sri K.C. Balaji for their valuable contributions to the development and maintenance of the database.

Besides, we are very thankful to the Chairperson and Members of the Local Project Advisory Committee (LPAC) for their valuable advice in carrying out this study. We express our sincere gratitude to Dr. Akhilesh Gupta (Advisor & Head, PCPM Division, DST), Dr. Parveen Arora (Head NCSTC, DST), Dr.H.B.Singh, Scientist-E, CHORD, DST, and Mr. P.K.Arya (Scientist, DST) for their valuable guidance to the completion of this project.

We thank Padmashree (Late) Dr. Baldev Raj, former Director, IGCAR, for initiating the project. He was instrumental in creating the contacts necessary for collecting the research output data from the institutes in India working on Materials and Metallurgy. Further, we thank Dr.U.Kamachi Mudali, Dr. R.K.Dayal, Dr. M.Valsan, and Sri. R.V.Subba Rao from IGCAR for their contribution to the project by collecting and analyzing the research data.

The project was successful due to the continued motivation and guidance given by Dr. B.Venkatraman, Distinguished Scientist, Director, IGCAR.

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List of Abbreviations

ASTM	American Society for Testing and Materials
BARC	Bhabha Atomic Research Centre
CGCRI	Central Glass and Ceramic Research Institute
CHORD	Centre for Human and Organisational Resource Development
CVD	Chemical Vapor Deposition
DAE	Department of Atomic Energy
DDW	Data-Driven Website
DM	Dimensional modelling
DST	Department of Science and Technology
EBSD	Electron Backscatter Diffraction
FAIR	Findable, Accessible, Interoperable, and Reusable
IGCAR	Indira Gandhi Centre for Atomic Research
IIS	Internet Information Services
IITK	Indian Institute of Technology, Kanpur
IITM	Indian Institute of Technology, Madras
IITR	Indian Institute of Technology, Roorkee
ISO	International Organization for Standardization
LPAC	Local Project Advisory Committee
MDDB	Multi-Dimensional Database
MDI	Materials Database of India
NDE	Non-Destructive evaluation
NIC	National Informatics Centre
NIMS	National Institute for Materials Science
NITK	National Institute of Technology, Karnataka
NML	National Metallurgical Laboratory
NSTMIS	National Science and Technology Management Information System
OLAP	On-Line Analytical Processing
OWL	Web Ontology Language
PFBR	Prototype Fast Breeder Reactor
PVD	Physical Vapor Deposition
RDCIS	Research and Development Centre for Iron and Steel
STQC	Standardization Testing and Quality Certification
VNIT	Visvesvaraya National Institute of Technology
XML	eXtensible Markup Language

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Executive Summary

Many scientific databases are available for materials data internationally. The data in those databases are generated in various research centres in their respective countries. China, Japan, USA and Canada have developed data stores. India is one of the leading contributors to Materials and Metallurgical data globally. However, the valuable data available is scattered in different institutional publications and reputed international journals and is not available in one place or in a quickly retrievable format. When an attempt was made to collect the already published data in the areas of mechanical and corrosion properties of materials, it was realized that the data generated within the country is of high value and very useful to the industries and scientific community if stored in one common place and utilized.

In this project, IGCAR would collect already published data and collate it into a database.

Objectives of the study

Scholarly data of an institution need to be preserved and made available to all. The Indian government and worldwide movement are for centralized repositories. In this project, an attempt was made to develop a Materials Database for India.

IGCAR had the confidence to collect data from premier institutes researching on structural materials since IGCAR has collaborations with many institutions doing research on Materials. Large sources of data on Creep, Fatigue, Tensile, Fracture and Corrosion properties on different structural materials generated in Indian laboratories will be collected.

The operation, maintenance, further developments and complete administration of the database would be by IGCAR. It was decided to host the data in an exchangeable format on the internet so that repetition of the same experiments is not done, thus saving cost & time. The extensive database will be beneficial to industries, students and research scholars.

Database Design

IGCAR collected research output data from Indian research centers and academic institutes. On studying the data, it was found, that the data essentially consists of the metadata part, which has the same set of fields for all data records. But the experimental output is different for every material and the property tested. After many rounds of discussions, the multidimensional data model was selected to use in the design of the database. The usage of MDDB solved the problem of making changes to the database whenever a new material with different property had to be included without changing the core dimensional data structure of the database.

Detailed Data-Driven Website Design

The Indian Materials Database is designed as a multidimensional data model. Dimensional modeling (DM) is a logical design technique often used for the data warehouses. It seeks to present the data in a standard, intuitive framework that allows for high-performance access. MS SQL server is used for storing data. The web application comprises dynamic and data-driven pages developed using Microsoft's ASP.net technology.

Although the entire data deals with materials and their properties, it is heterogeneous in terms of properties studied of a specific material, material types studied with respect to a property, conditions underwent by a material before testing, and test details. The data on a property can be in tables, graphs, microstructure images, or a combination of these. Even though the research data is stored in a single database, the display of data should satisfy all users interested in various aspects of the available data.

The user's priorities in searching the data can be any of the following:

1) Search for a Material: A user may access the database seeking data on a particular material type he is interested in. For a single material, the data on various properties of the different types and subtypes of the materials obtained from multiple sources are available in the database.

2) Search for a Property: The database user may be interested only in data regarding a specific material property. The data about different material types are available in the database for any single property.

3) Search for source of data: Since the database is a compilation of data from different organizations, the user may be interested in data from a particular organization or published in a specific journal or year of publication.

4) Search for Type of data: The data on a material property is available in the form of tables, graphs or microstructure images. Sometimes, a user may be concerned about data of a particular form only, i.e. he may want to retrieve all the graphs available on material properties and so on.

Once the user views a web page with material property data, he may want to save it in an exchangeable format for future use. The application provides an option to save the data in XML (eXtensible Markup Language) format. The user's interactions with the web application are shown in the UML use case diagram in Figure. 1.

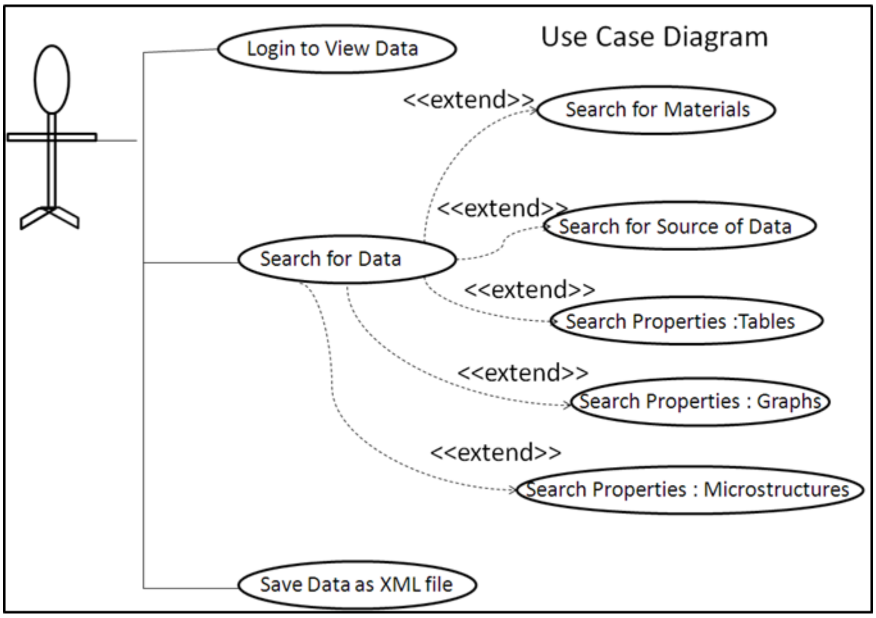

Figure 1 : Use case Diagram of Materials Database

Data Collection from Premier Institutes of India and hosting on website

This is the first pioneering work where data from various institutions are collected. Few research institutes agreed to share already published data. The participating institutes are Bhabha atomic research centre (BARC), National Metallurgical Laboratory (NML), Research and Development Centre for Iron and Steel (RDCIS), Central glass and Ceramic Research Institute (CGCRI), Indian Institute of Technology, Roorkee (IITR), Indian Institute of Technology, Kanpur (IITK), Visvesvaraya National Institute of Technology (VNIT), National Institute of Technology, Karnataka (NITK), Indian Institute of Technology, Madras (IITM) and IGCAR.

Brief Description of the data

Indian Material Database covers physical, corrosion and mechanical properties of metallic and non-metallic materials. The information is available in the form of tables, graphs and microstructures with corresponding references. In the database, the search is based on materials and properties.

Materials

Data on metallic materials cover **Ferrous and Non-ferrous alloys**. Ferrous materials include Duplex stainless steel, Maraging steels, Microalloyed steels, carbon steels, mild steel, High Strength Low Alloy steel, Austenitic stainless steel, Ferritic-martensitic steels and their weld joints. **Non-Ferrous materials include** Ni-base superalloy, Titanium alloys, Zirconium alloys, Niobium alloys, Binary alloys of Nickel, Aluminum and Copper etc. **Non-Metallic materials** include coatings, thin films, Nanocrystalline oxide multilayers, Nitrides and silica glasses. There is also information on composites such as metal matrix composites, Glass-polymer composite and nano-composite coatings.

Material Properties

The database incorporates **corrosion properties** such as biofouling, microbial corrosion, pitting corrosion, general corrosion, Sodium corrosion, sensitization and high temperature corrosion. **Mechanical properties** available are tensile, creep, various types of fatigue failure, creep-fatigue interaction, impact, hardness, microhardness, nano-mechanical behaviour, superplasticity, fracture toughness and crack growth behaviour.

Data Collection

Experimental Data from conventional and small specimen testing were covered in the material database. Data is available from the following areas like creep, fatigue and creep-fatigue interaction behaviour of various steels, studies on the influence of welding techniques on microstructure and mechanical properties of ferritic steel weldments, Zone wise creep behaviour in weld joints, application of AI techniques in weldability studies, Hot deformation studies on austenitic steel, fatigue crack growth studies on ferritic and austenitic stainless steels, Type-IV cracking problem, influence of aging on mechanical properties etc.

Data on Inconel alloys for future coal fired power plants is also included. Database also covers modeling studies on deformation and damage behaviour under creep, fatigue, tensile at different length and time scales up to atomistic simulations.

Structure-property correlations using conventional and advanced characterization techniques such as EBSD, In-situ Raman Scattering and XPS, studies on various NDE techniques including ultrasonic guided wave inspection methodology for steam generator tubes in PFBR have been incorporated.

Corrosion studies include behavior of alloys in various electrolytes, nano-metal oxide coating to resist biofouling, Materials study for nuclear reprocessing applications & evaluation of corrosion resistance of nano-nickel-ferrite and magnetite double-layer coatings on carbon steel. Phase transformations, nano-fluid magnetic sensors and interface studies are also covered.

Results & Discussions

In 2017, the website of the materials database was hosted in National Informatics Centre (NIC). To host the website in NIC cloud, application security auditing by a third party was mandatory. It was done by STQC, IT Chennai.

The database is a precious source of research data helpful to industries, students and research scholars. The worldwide open science initiative is gaining momentum. The material database of India is a standing example of open science data. Sustaining the activity by continuing data collection and updating the database would be very fruitful.

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Chapter 1: Introduction

Indira Gandhi Centre for Atomic Research (IGCAR), with funding and support from CHORD, NSTMIS, DST, has taken up an ambitious project to develop an Indian Materials Database by bringing together the materials property research data from different organizations in India and collating into a database. Indian laboratories generate research data on Mechanical, Corrosion, Non-destructive Evaluation, Thermal and Optical properties of materials used in power, space, nuclear and chemical industries as per international ASTM standards. This project is a pioneering attempt to compile such research data and make it available to the scientific community to reuse without repeating the same experiments. A unique feature of this data storage will be its authenticity since it solely consists of data published in reputed peer-reviewed publications.

Objectives

Scholarly data of an institution need to be preserved and made available to all in the FAIR (Findable, Accessible, Interoperable, and Reusable) mode. Research data being shared for reuse is the open science concept. The main objective is the development of a Materials Database for India. IGCAR would do the collection of data from premier institutes of India. Experts in the field of Metallurgy would collate the data into a database. The experimental output should be freely available for download in an exchangeable format so that repetition of the same experiments is not done, saving cost, man power, infrastructure and time. The extensive database will be useful to research scholars, industries and students.

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Chapter 2: Review of Literature

The objective of collating data to form a materials database is to make the research data available open in an exchangeable format to students and research scholars to reuse in their research. In this connection, a literature survey was done for the available standards, materials data structure, the semantic web related ontology data, website vulnerabilities in case of a dynamic website, etc.

There is already an ISO 10303 international standard for representation and exchange that specifies information models for computer-interpretable representation for exchangeable engineering products [1]. The standard explains the engineering properties for product design and verification for the computer representation and exchange of material and any other engineering properties of a product and provides an audit trail for the derivation of the property value in depth.

Standardized definitions of higher-order concepts are required to formalize and share knowledge about materials. MatML is a standard data schema for the material data exchange [2]. Here XML is used for the data exchange. MatML has data representation and schema that makes heterogeneous databases and structures interoperable.

An approach to transform MatML-based material data to OWL ontology is necessary to explore the materials data more semantically. The instance transformation from MatML to MatOWL is implemented with the help of an intermediate object model [3]. Doo-Man Chun et al. discuss the next stage toward knowledge management about material usage, selection or processing, defining an ontology that represents the structure of concepts relating to materials.

There are other materials selection techniques and structure-aware query techniques XPath and XQuery. Using these techniques an approach to transform materials data into an OWL ontology is proposed [5]. XQuery provides an extensible framework that encapsulates the top level structured knowledge of materials science. Plant engineers for material selection and failure analysis require environmental details of the materials like the chemical composition, corrosion characteristics, physical properties, mechanical properties, standards and all the test cases [6]. The material database developed in this project has incorporated the properties data in addition to the standards and test cases.

The heterogeneous materials database integration using federal database or data warehousing techniques are not readily available due to lack of semantic description [7]. The heterogeneous databases are integrated to the ontology using relational algebra and rooted graphs. The semantic query is executed using SPARQL.

There is a detailed discussion on a prominent class of methods that can use existing access structures called 'space filling curves' since efficient management of multidimensional data is a challenge when building modern database applications [8]. This method connects the regions of sizes rather than the points in multidimensional space. The approach transforms the interval queues into regions of data which results in significant improvements in accessing the data.

However, indexing the relational databases when they have multiple dimensions is very time-consuming. The stored procedures and triggers can be combined to a multidimensional index structure to make the retrievals very cost-effective [9].

Scanning and filtering over multidimensional tables are key operations in modern analytical database engines. Indexing multidimensional databases use clustered indexing and R-Trees and Z-ordering for sorting to optimize the performance of these operations. A new Flood indexing that optimizes multidimensional indexes adapts itself to a particular dataset and workload by jointly optimizing the storage structure and indexing [10].

Many material databases are available globally. It was found that MatWeb [11] is a searchable materials database. The searches were through material class and advanced search, which includes the material subtype and test conditions, search through the property, etc. Further, all the selected criteria are displayed together. These were valuable inputs incorporated in the Materials database developed in our project. Matnavi is the materials database from National Institute for Materials Science (NIMS)[12]. They are enhancing their website continuously. The searches in this database is based on materials class and properties. The data structure is developed for further analysis. The

Springer LB Materials database is subscribed by IGCAR [13]. It contains very valuable materials research data. The study of the Vamas [14] website has given further insight into materials database development.

In database web applications, the common vulnerabilities are the SQL injections, cross-site scripting, insecure direct object reference, etc. and the precautions to overcome them [15] are discussed with illustration.

The multidimensional database model can be built using relational database. Materials databases using multidimensional database is discussed in this article [16]. The dimensions can be treated as metadata necessary for search is explained [17]. Using XML for data transfer from a website is also illustrated.

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Chapter 3: Methodology

Collection of Data

IGCAR has collaborations with every institute researching materials in India. Institutes doing basic research in Metallurgy & Materials that understood the objective of the project have participated in this project. Every participating organization has identified a nodal officer to coordinate with their respective organizations to send data. The participating institutes are the premier institutes of North, East, West and South zones of India. The participating institutes are Bhabha atomic research center (BARC), National Metallurgical Laboratory (NML), Research and Development Centre for Iron and Steel (RDCIS), Central glass and Ceramic Research Institute (CGCRI), Indian Institute of Technology, Roorkee, (IITR), Indian Institute of Technology, Kanpur,(IITK), Visvesvaraya National Institute of Technology (VNIT), National Institute of Technology, Karnataka (NITK), Indian Institute of Technology, Madras, (IITM) and IGCAR.

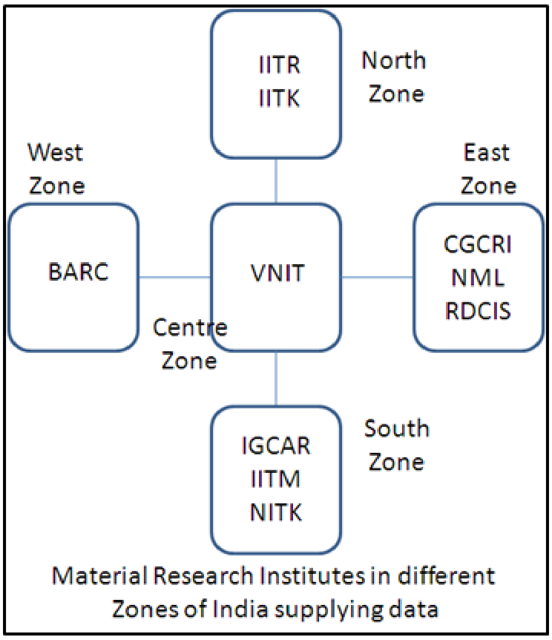

Figure 2: Participating institutes

Database Design

Designing database is identifying the data, defining specific data types and ensuring data integrity. The different properties that are found in the database ranges from Mechanical Properties (Low Cycle

Fatigue, Thermo-mechanical Fatigue, Tensile, Hardness, Creep, Fatigue Crack Growth, Dynamic Fracture Toughness, Creep Crack Growth etc), Corrosion Properties (Sensitization, Hydrogen Transport, Pitting, Sodium Corrosion, Biofouling, High-Temperature Corrosion etc), Non-Destructive Evaluation or Characterization studies (Results of Eddy Current Testing, Ultrasonic Spectroscopy), Optical and Thermal Properties etc. The database consists of properties on Austenitic Stainless Steel (Grain Size (316), Heat To Heat Variation (316), Thermal Ageing (Weld Joint(316 & 316LN), Weld Metal (316 & 316LN), Cold Work (304, 316), Ti/C Ratio (D9), Ferritic Steel, Nickel, Titanium Alloys, Zirconium Alloys, etc. Moreover, a Graphical representation of the above properties and the microstructures of the material after testing are given on the website.

The database presently consists of 60 material types and 275 material subtypes. There are 72 properties pertaining to the materials and more than 500 journal data. The test conditions used is in the range of 520. 1533 graphs and 1710 microstructures are present in the database. It was necessary to design a database model to hold all these materials and their respective properties. The database design should be robust to accept future entries without modification to the database structure.

Case Study

Proof of concept was done through a case study. The study was based on data generated in IGCAR laboratories. Data on Mechanical properties like tensile, creep, fatigue and corrosion properties like pitting, sensitization, biofouling at different temperatures and metallurgical conditions for various austenitic steels, ferritic steels and Ti & Zr alloys were collected and a database was built. A prototype web application was developed. The different steps like data design, application logic and presentation design were done. Basic access control logics were implemented.

Web application was made secure by hardening of Operating System, hardening of the Web Server software, and ensuring strict security rules in the application development.

During this phase, it was decided the data would be stored in databases. The database had to be designed to hold many types of materials, and their properties.

The inadequacy of using a relational database was found when more materials and properties were included. With a good data design, the material data access has to become fast, easily maintained, and can gracefully accept future data enhancements.

Senior Metallurgist , Dr. V.S. Srinivasan is a Co-PI in collaboration with other experts in the field has segregated the data and classified it into metadata necessary to reuse the experimental results and the experimental output data. It was found the metadata had similar fields for all properties as seen in Figure 3. Only the experimental outputs were different.

The database model was chosen after detailed study on how the data search would be provided in the website. Study of already existing websites and materials classification pattern has given the necessary inputs. Material database visibility is enhanced by providing searches on materials class and material property data. Our website also contains information as to when the material was first published and the name of the journal, citation etc. Also the research output data is available as table data, graphs and microstructures.

Metadata
Material Class
Material Type
Material Property
Chemical Composition
Material History
Material Standard
Material Test Conditions
Material Source Journal name, Year of Publication, Authors, Title

Figure 3 : Metadata

The materials database was implemented using multi dimensional database (MDDB) model.

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Chapter 4. Detailed Design

Multidimensional Data Model

The task was to develop a database that can accommodate any new material or property and the output data from experiments without a change in the database structure. Additional desirable qualification would be ease of querying of data through the website. Multidimensional data models integrate massive amounts of data and they are suitable for OLAP (on-line analytical processing), data mining, etc. Table structures are simple, standardized and de-normalized to allow storage as well as fast access of data.

Dimensional modeling is a logical design technique and it is actually an extension of the relational database model. One of the popular dimensional modelling schema "the star schema" as depicted in Figure 4 is used to explain the dimensions of the material database.

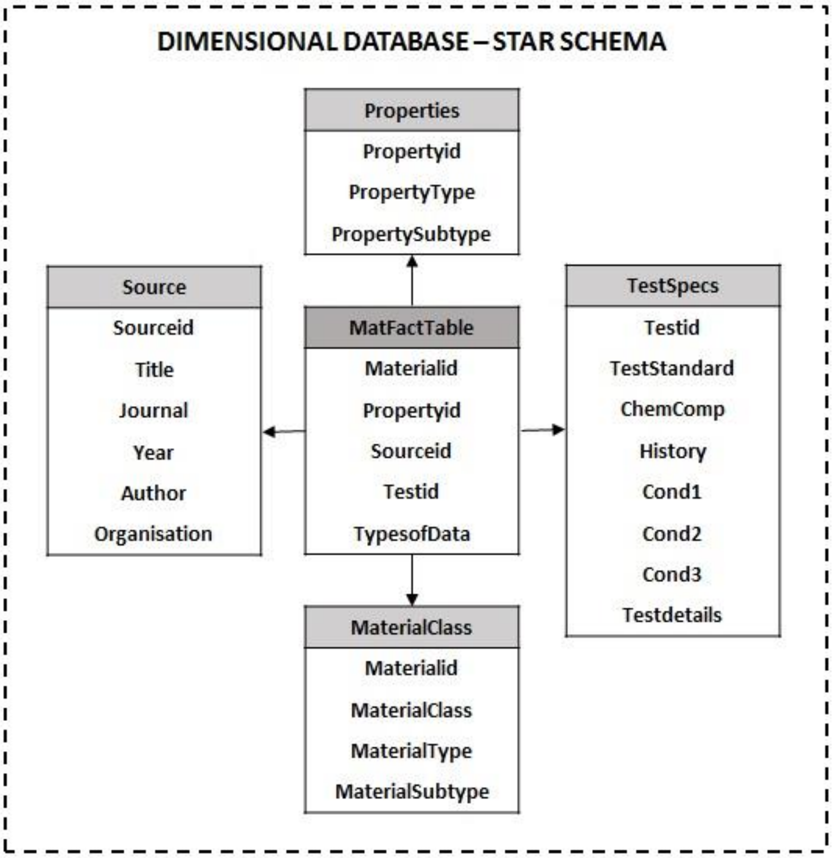


Figure 4 : Star Schema of Materials Database

In the Figure 4, the dimensions are chosen as the material type, material property tested and the citation details of the journal which is the source of the data. The Materials dimension consist of material type, subtype, class and material id which is the foreign key to the fact table. The Property dimension consists of the materials property, its test criteria, sub property etc. The Testspecs dimension consists of details on tests and duration of the tests. The Source dimension consists of data on the journal name and other citation details of the data. The fact table (MatFactTable) contains the primary keys corresponding to the foreign keys of each of the four dimensions.

The experimental output data available on each material property is in the form of tables, microstructures or graphs. This data cannot be accommodated in star schema. So to include the research output data, the star schema is extended to snowflake schema. In the snowflake schema, sub-dimensions can be created to one or more of the dimension tables. In the material database, the test results are stored as tables and they form the extensions or the snowflakes of the Testspecs dimension. The snowflake schema structure of our Materials database is shown in Figure 5.

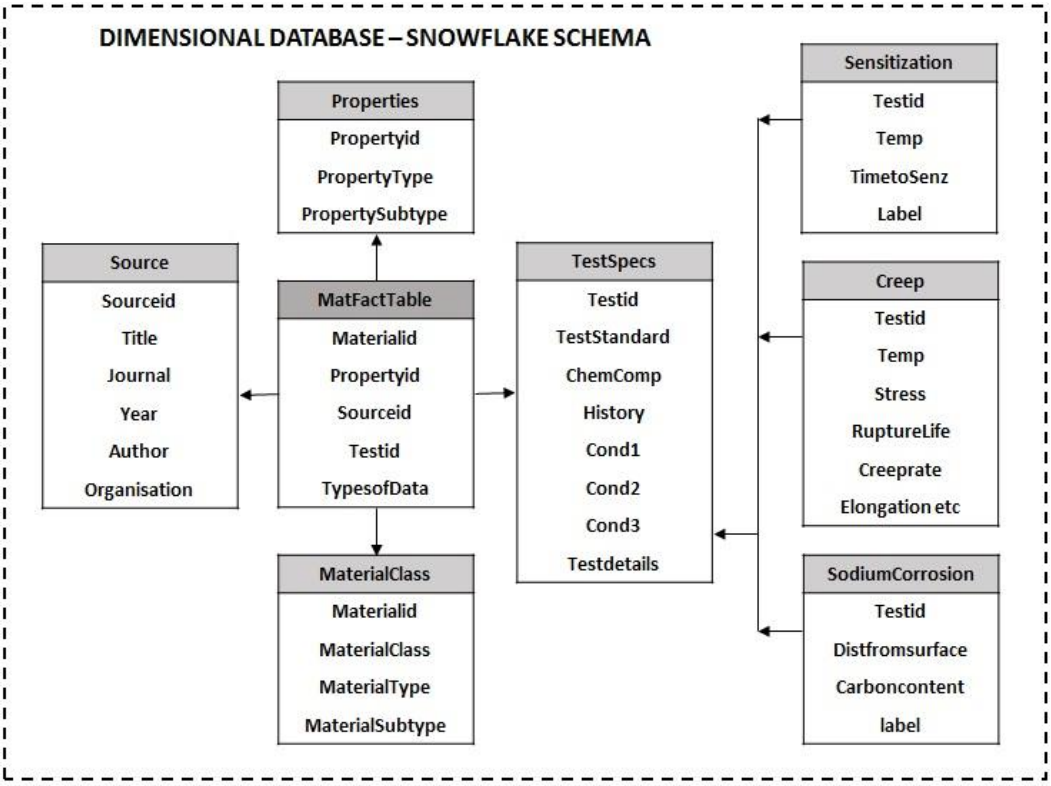


Figure 5 : Snowflake Schema

The experimental data in some cases are available as tables or graphs and in some other cases microstructure. All are part of the snowflake schema. The dimensional models are used where data can be identified by more than one entity in our case by the data from the material dimension or property dimension or source dimension. The snowflake schema is a common method used to represent multi-dimensional data with some unknown data factor, like in our case the experimental output is different with each material and its property tested. In our website, we use the materials type, materials property and source dimensions as search criteria and as data is added the metadata gets built without additional effort.

Based on the study on different websites on materials across the globe and discussions with experts in the field of Metallurgy, the search on the database is incorporated in the materials website, such as Search by a Material, Search by a Property, Search by Source of Data and Search by Type of Data (Microstructures or Graphs or Tables) and is shown in Figure 6.

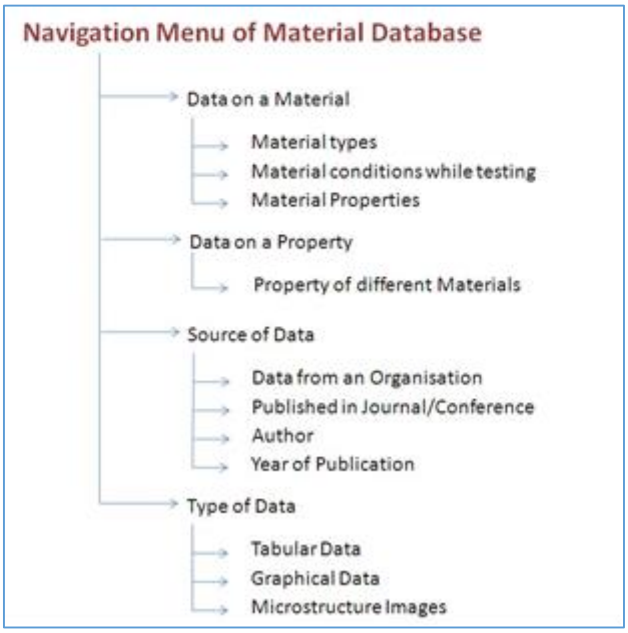


Figure 6 : Navigation menu of Material Database

Website Design and Features

The success of website depends upon effective and efficient web designing. The web designing is the spirit of website and solely depends upon the layout, structure and compilation of the content.

Websites are planned in a precise manner to cater to specific need. Materials database of India (MDI) is a dynamic website. It means the data displayed on the webpage changes with the user's selection of search criteria. The MDI website is designed as a fully Data Driven Website (DDW). DDW are independent of addition or modification of entirely new materials or property data that is not so far available in the database. Also addition of such data to the databases do not need any changes to be made to the Web Page.

To increase the visibility and the speed of accessibility of data in a website, every website provides data called metadata. This metadata is keywords to a journal paper, content page to a book or the expiry date, price, manufacturer and composition to a medicine. This acts as a catalyst to find the data available in the website and to reach it. With every new data added to the website, this metadata has to be updated. The present-day trend is to make this metadata grow automatically with the addition of new data to the database. This is made possible in our website by designing the database structure efficiently. In our website, material class, material property, source and type of data are the metadata . These are the fields used to search data in the website. These are the dimensions of the multi dimensional database designed by us. So every time a material data is added to the database, the dimensions are populated which are our metadata ensuring auto-generation of metadata.

The website is designed to reduce vulnerability from hackers. The dynamic pages are kept as minimum as possible. The web application constitutes eight data-driven web pages. There are five pages for the searches on the database, i.e., materials, properties, graphs, microstructures, and source. Three web pages are there to access the data of each type, i.e. table data, graph data and microstructure data. The user can arrive at a data by searching for the material or property or source of data. The opening page of website where the search criteria is visible on the right is seen in Figure 7

Figure 7 : Webpage of Materials Database of India

The features of the website are given clearly in a Use case diagram Figure 5. Use case diagrams are used to tell the actions (use cases) to be done by an external user to use the concerned system. Such diagrams help in explaining as well as in developing the website. In our case, the use case diagram explains, to view data every user has to register in the website. Registered user can view table data, graph data and microstructure data. Data may be searched based on material class, material type, source and property. The data is available in the form of microstructures, graphs and tables. In the figure 8 << extend>> implies an action has to be done by the external user like a mouse click to proceed further. The retrieved data is available to the external user for download in XML format.

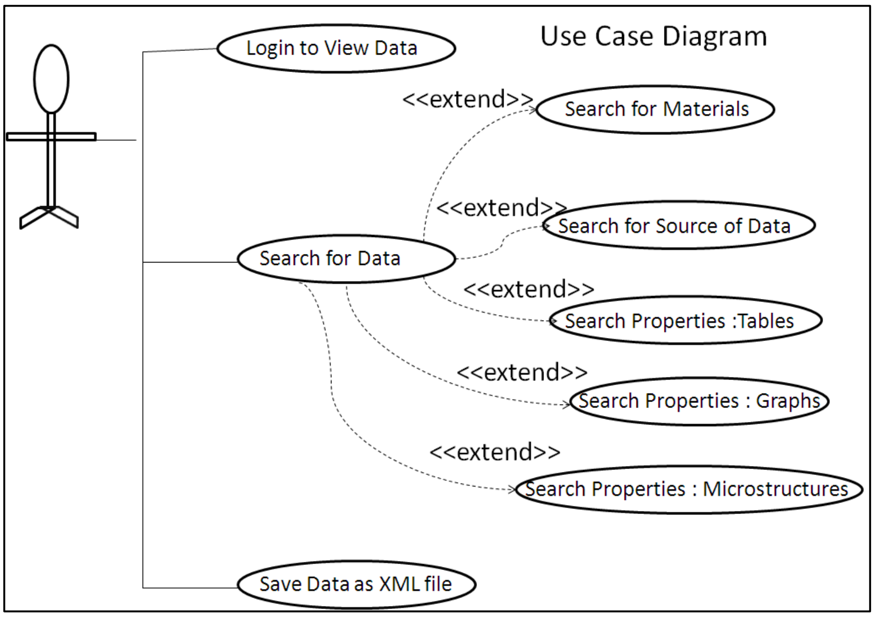
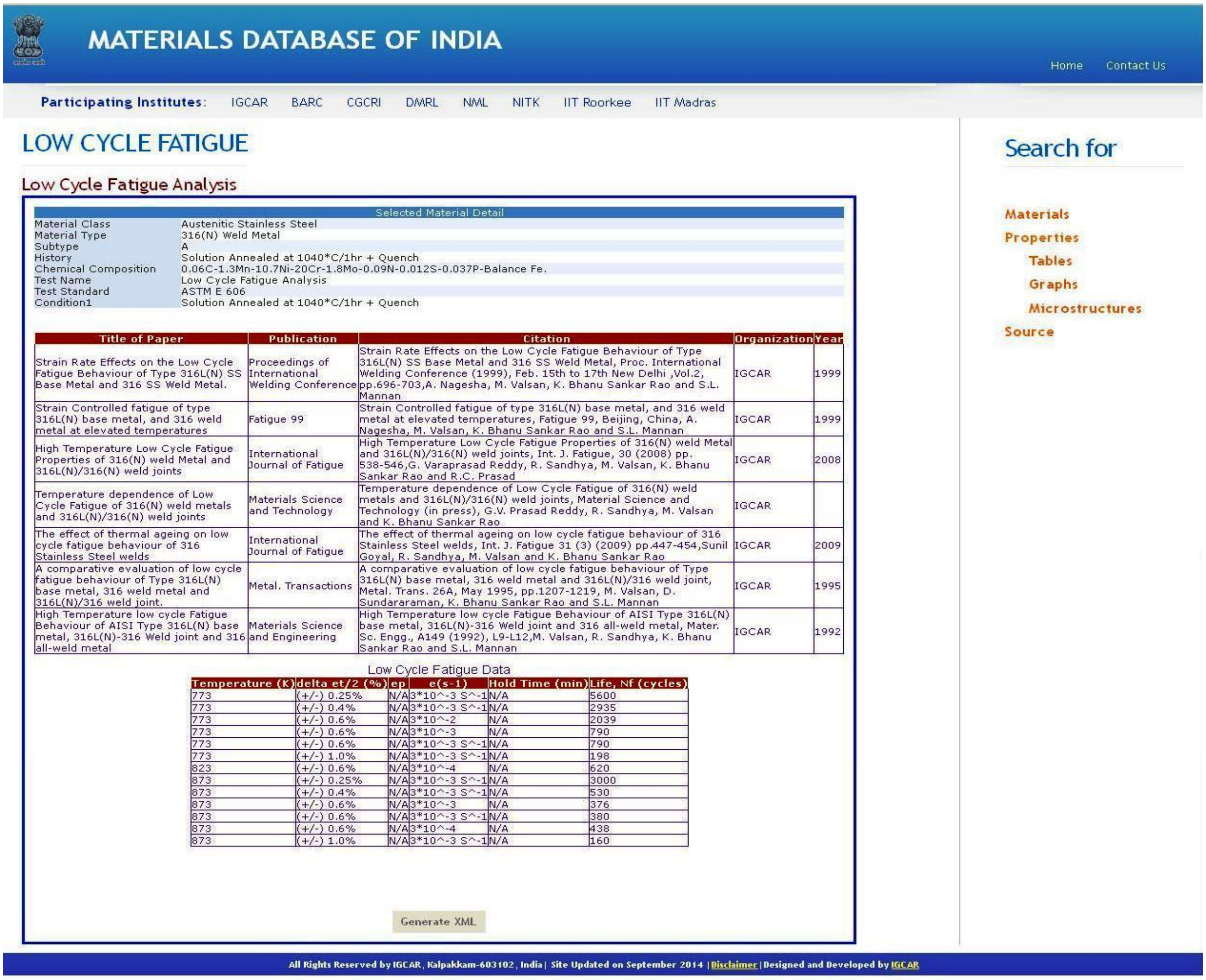


Figure 8 : Use Case Diagram of Materials database

The database used is MS SQL Server with IIS Web server and the web pages are developed using ASP.Net The website was hosted in National Informatics Centre (NIC). NIC is a government of India institute providing network backbone and e-Governance support to Central Government and State Governments of India. Soon the Materials Database of India would be added to the institutional repository of IGCAR.

The total selection criteria is displayed in the website (Figure 9) along with the output data. The website has a visitor count of above 43000 .


MATERIALS DATABASE OF INDIA

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Participating Institutes: IGCAR BARC CGCRI DMRL NML NITK IIT Roorkee IIT Madras

LOW CYCLE FATIGUE

Low Cycle Fatigue Analysis

Selected Material Detail	
Material Class	Austenitic Stainless Steel
Material Type	316(N) Weld Metal
Subtype	A
History	Solution Annealed at 1040*C/1hr + Quench
Chemical Composition	0.06C-1.3Mn-10.7Ni-20Cr-1.8Mo-0.09N-0.012S-0.037P-Balance Fe.
Test Name	Low Cycle Fatigue Analysis
Test Standard	ASTM E 606
Condition1	Solution Annealed at 1040*C/1hr + Quench

Title of Paper	Publication	Citation	Organization	Year
Strain Rate Effects on the Low Cycle Fatigue Behaviour of Type 316L(N) SS Base Metal and 316 SS Weld Metal.	Proceedings of International Welding Conference	Strain Rate Effects on the Low Cycle Fatigue Behaviour of Type 316L(N) SS Base Metal and 316 SS Weld Metal, Proc. International Welding Conference (1999), Feb. 15th to 17th New Delhi ,Vol.2, pp.696-703,A. Nagesha, M. Valsan, K. Bhanu Sankar Rao and S.L. Mannan	IGCAR	1999
Strain Controlled fatigue of type 316L(N) base metal, and 316 weld metal at elevated temperatures	Fatigue 99	Strain Controlled fatigue of type 316L(N) base metal, and 316 weld metal at elevated temperatures, Fatigue 99, Beijing, China, A. Nagesha, M. Valsan, K. Bhanu Sankar Rao and S.L. Mannan	IGCAR	1999
High Temperature Low Cycle Fatigue Properties of 316(N) weld Metal and 316L(N)/316(N) weld joints	International Journal of Fatigue	High Temperature Low Cycle Fatigue Properties of 316(N) weld Metal and 316L(N)/316(N) weld joints, Int. J. Fatigue, 30 (2008) pp. 538-546,G. Varaprasad Reddy, R. Sandhya, M. Valsan, K. Bhanu Sankar Rao and R.C. Prasad	IGCAR	2008
Temperature dependence of Low Cycle Fatigue of 316(N) weld metals and 316L(N)/316(N) weld joints	Materials Science and Technology	Temperature dependence of Low Cycle Fatigue of 316(N) weld metals and 316L(N)/316(N) weld joints, Material Science and Technology (in press), G.V. Prasad Reddy, R. Sandhya, M. Valsan and K. Bhanu Sankar Rao	IGCAR	
The effect of thermal ageing on low cycle fatigue behaviour of 316 Stainless Steel welds	International Journal of Fatigue	The effect of thermal ageing on low cycle fatigue behaviour of 316 Stainless Steel welds, Int. J. Fatigue 31 (3) (2009) pp.447-454,Sunil Goyal, R. Sandhya, M. Valsan and K. Bhanu Sankar Rao	IGCAR	2009
A comparative evaluation of low cycle fatigue behaviour of Type 316L(N) base metal, 316 weld metal and 316L(N)/316 weld joint.	Metal. Transactions	A comparative evaluation of low cycle fatigue behaviour of Type 316L(N) base metal, 316 weld metal and 316L(N)/316 weld joint, Metal. Trans. 26A, May 1995, pp.1207-1219, M. Valsan, D. Sundararaman, K. Bhanu Sankar Rao and S.L. Mannan	IGCAR	1995
High Temperature low cycle Fatigue Behaviour of AISI Type 316L(N) base metal, 316L(N)-316 Weld joint and 316 all-weld metal	Materials Science and Engineering	High Temperature low cycle Fatigue Behaviour of AISI Type 316L(N) base metal, 316L(N)-316 Weld joint and 316 all-weld metal, Mater. Sc. Engg., A149 (1992), L9-L12,M. Valsan, R. Sandhya, K. Bhanu Sankar Rao and S.L. Mannan	IGCAR	1992

Low Cycle Fatigue Data

Temperature (K)	delta et/2 (%)	ep	e(s-1)	Hold Time (min)	Life, Nf (cycles)
773	(+/-) 0.25%	N/A	3*10^-3 S^-1	N/A	5600
773	(+/-) 0.4%	N/A	3*10^-3 S^-1	N/A	2935
773	(+/-) 0.6%	N/A	3*10^-2	N/A	2039
773	(+/-) 0.6%	N/A	3*10^-3	N/A	790
773	(+/-) 0.6%	N/A	3*10^-3 S^-1	N/A	790
773	(+/-) 1.0%	N/A	3*10^-3 S^-1	N/A	198
823	(+/-) 0.6%	N/A	3*10^-4	N/A	620
873	(+/-) 0.25%	N/A	3*10^-3 S^-1	N/A	3000
873	(+/-) 0.4%	N/A	3*10^-3 S^-1	N/A	530
873	(+/-) 0.6%	N/A	3*10^-3	N/A	376
873	(+/-) 0.6%	N/A	3*10^-3 S^-1	N/A	380
873	(+/-) 0.6%	N/A	3*10^-4	N/A	438
873	(+/-) 1.0%	N/A	3*10^-3 S^-1	N/A	160

Generate XML

Search for

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Figure 9: Sample webpage of http://mdi.nic.in

Web Security Auditing

In 2017, the website was hosted on to the National Informatics Centre(NIC). NIC follows cloud architecture where the website is hosted. It is mandatory to conduct website application security auditing every three years. In 2017, the web security auditing was conducted at STQC. The vulnerabilities listed by STQC were corrected.

Brief summary of the Data on the database

Collection of data is from organizations like BARC, NML, NITK, IIT Roorkee, CGCRI, DMRL, IIT Madras and RDCIS Ranchi who after interactions and discussions provided the data on mechanical and corrosion properties of various materials of interest to their respective institutes.

A sample of the data obtained from various Institutions is given below, this is not the complete list.

IGCAR Data

- The Table of data consists of following properties of austenitic and ferritic steels:

  Tensile, Creep, Fatigue (Low Cycle Fatigue, Creep Fatigue, Thermo Mechanical Fatigue), Hardness, Corrosion (Uniform, Sensitization, Pitting, Hydrogen damage, High Temperature oxidation, Sodium corrosion, Biofouling), Non Destructive Testing Techniques (Ultrasonic Spectroscopy, Eddy Current Testing).

- The graphical data are from the following areas of Mechanical properties Tensile, Fatigue, Low Cycle Fatigue, Creep Fatigue, Thermo Mechanical Fatigue whereas microstructural data corresponds to Tensile and Fatigue (Low Cycle Fatigue, Creep Fatigue, Thermo Mechanical Fatigue) properties.

- The materials data base has been updated with data on Fatigue crack growth, dynamic fracture toughness, quasi-static fracture toughness and creep crack growth.

- Fatigue crack growth studies carried out on ferritic steel namely 9Cr-1Mo and Mod.9Cr-Mo steel and austenitic stainless steel 316L(N) weld metal and aged weld metal

- Dynamic fracture toughness determined on 9Cr-1Mo steel, Mod.9Cr-1Mo weld metal and base metal, armour grade steel and armour grade steel weld joint

- Quasi static fracture toughness of Mod. 9Cr-1Mo steel and Creep crack growth studies on 316(N) austenitic steel weld metal.
- Properties of thin films (CVD coatings and PVD coatings) namely Hardness, Nano mechanical properties, corrosion properties, thermal properties, Optical properties, resistivity, process parameters used in thin film making and microstructural properties has been loaded into the data base.
- Studies conducted on hard phasing alloy colmonoy 5 and columnoy 6, repair weld studies on martensitic stainless steel AISI 414 type and studies conducted on properties of modified 9Cr-1Mo ferritic steel weld have been incorporated into the data base.

NML Data

The data on mechanical and corrosion properties on the following materials from National Metallurgical Laboratory, Jamshedpur has been added to the data base:

- Tensile and impact properties of HSLA -100 grade steel,
- Tensile, wear and hardness properties of Al alloy A356
- Tensile and hardness properties of Al base short steel fiber reinforced composites
- Hardness and wear properties of Electroless Ni-B coating
- Tensile, creep and hardness of G-911 ferritic steel
- Compression properties of SiC in 2014 Al alloy-metal matrix composites
- Tensile and creep of 1Cr-0.5Mo steel ferritic steel
- Shear stress of Sn-Ag-Cu solder alloy
- Wear and hardness of Ni-P/Ni-B duplex coatings
- Tensile and fatigue crack growth of Railway wheel steel
- Tensile and hardness of BS 3059/45 mild steel

- Fretting corrosion of Sn plated Cu alloy
- Uniform corrosion of 304L austenitic stainless steel

NITK Data

The data on mechanical and corrosion properties from NITK has been added to the data base.

- Tensile properties of austempered ductile iron
- Dynamic fracture toughness of 316 TIG weld
- Compression properties of Al-Zn alloys and Ti-6Al-4V
- Creep properties of Sn-40% Pb
- Wear properties of austempered ductile iron
- Uniform corrosion of ductile iron
- Hardness properties of nano structured FeAl intermetallics

BARC Data

The data on mechanical and corrosion properties BARC has also been appended to the data base:

- Delayed hydride cracking, tensile properties, superplasticity, hydride blister formation and hydride embrittlement of Zr-2.5%Nb alloy
- Dynamic fracture toughness and hydride embrittlement of Zircaloy 2
- Hydride embrittlement of Zr-0.5%Y alloy
- Uniform corrosion of A333 grade carbon steel
- Low temperature embrittlement of 2205 duplex stainless steel
- High temperature oxidation of Zircaloy 2 and Zr-Nb alloys
- Uniform corrosion of 304 L SS

- Failure analysis of 90/10 cupronickel and carbon steel A106 grade B, SA 213-T22 plain carbon steel.
- Stress corrosion of 304L SS
- Low temperature sensitization on IGSCC of 304 L and 304 LN
- Fracture toughness (sensitization effect) of 304LN SS

CGCRI Data

- Nanomechanical properties of coating-hydroxyapatite coating on 316L,
- microplasma sprayed hydroxyapatite coating, soda lime silica glass, composite-carbonfiber-carbon/carbon and carbon/carbon-SiC composite and Mechanical properties of Al_2O_3 ceramic (wear and hardness, fatigue crack growth, indentation fatigue),
- fracture toughness of hydroxyapatite coating,
- creep and indentation fatigue of silicon nitride
- Nanomechanical properties of coating-hydroxyapatite coating on 316L
- Mechanical properties-hardness- Al_2O_3 ceramic
- Nanomechanical properties of coating-microplasma sprayed hydroxyapatite coating
- Nanomechanical properties soda lime silica glass
- Mechanical property-tensile- sodalime silica glass/epoxy/polyvinyl butynol
- Nanomechanical property- composite-carbonfiber-carbon/carbon and carbon/carbon-SiC composite.
- Mechanical properties- wear- alumina ceramic
- Mechanical properties-hardness of Silicon Nitride, alumina and Silicon carbide
- Mechanical Properties-creep-Silicon Nitride

- Mechanical properties- fatigue crack growth- alumina
- Mechanical Properties- Indentation fatigue – alumina, silicon nitride, silicon carbide
- Mechanical Properties- Fracture toughness-hydroxyapatite coating
- Optical properties –Glass ceramics Li_2O-Ta_2O_5-SiO_2-Al_2O_3-Nd^{3+}-doped
- Thermal properties, Structural Properties, Optical property of – Glass Ceramic-CaO-La_2O_3-$B_2O_3^-$ with TiO_2
- Microstructural studies- Glass ceramics Li_2O-Ta_2O_5-SiO_2-Al_2O_3
- Microstructural studies, Thermal properties – Glass Ceramics - CaO-La_2O_3-B_2O_3
- Optical properties- Glass ceramic- SiO_2-CaO-Al_2O_3-MgO-NaF with Tb_2O_3 up to 40 Wt%
- Optical Properties- Glass Ceramic-Ba- Al- Metaphosphate glass dopped – Nd^{3+}-Yb^{3+}-Er^{3+}
- Optical properties- Glass Ceramic ZnO-B_2O_3 with Bi^{3+} co-doped Eu^{3+}
- Optical Properties –Glass Ceramic Pr^{3+} telurite glass
- Optical Properties- Glass Ceramic Boro-Fluro-Phosphate Glass Er^{3+}
- Optical properties-Glass Ceramic CaO-La_2O_3-B_2O_3 - Nd^{3+}-doped
- Optical properties-Glass Ceramic ZnO-B_2O_3 - SiO_2 –Tm_2O_3- Thallium doped
- Optical properties-Glass Ceramic Ba-Al-Metaphosphate laser glasses
- Charaterization-ultrasonic- glass ceramics 45SiO_2-55PbO glass,40P_2O_5-60MoO_3
- Optical Properties- glass ceramic CaO-La_2O_3-B_2O_3 - Eu^{3+}
- Optical Properties- glass ceramic- K_2O-B_2O_3-Al_2O_3-SiO_2-MgO-F
- Mechanical Properties-wear- glass ceramic- K_2O-B_2O_3-Al_2O_3-SiO_2-MgO-F
- Optical properties-Glass Ceramic-Li_2O-Ta_2O_5-SiO_2-Al_2O_3-Er^{3+} doped

- Optical Properties, Electrical Properties-Glass Ceramics- Li_2O-Ta_2O_5-SiO_2-Al_2O_3-Eu_2O_3

- Optical Properties-Glass Ceramics- SiO_2-BaF_2-K_2CO_3-La_2O_3-Sb_2O_3

The database presently consists of 60 materials and 275 material subtypes with 72 properties and more than 500 journal data. The test conditions used is in the range of 520, around 1533 graphs and 1710 microstructures are under use. The table-1 below includes the List of Materials found in the database.

• Al – Lithium Alloy	• Low Carbon Steel	• Sn Plated Cu alloy
• Al Alloys	• Maraging Steel	• Sn-Pb Alloy
• Al-Cu alloys	• Medium Carbon Steel	• Solder alloy
• Al-Zn Alloys	• Metal Matrix Composite	• Stainless Steel
• Austenitic Stainless Steel	• Metal Waste Form - SS-Zr (MWF)	• Steel
• Carbon Steel	• Mg alloy	• Superalloys
• Ceramics	• Microalloyed steels	• Thin Films
• Coatings	• Mild Steel	• Titanium Alloys
• Composites	• Nano Composite Coatings	• Transition Metal Nitride
• Concrete	• Nano Composite Thin Films	• Ultra High Strength Steel
• Copper Nickel Alloy	• Nanocrystalline Oxide Multilayers	• Zirconium Alloy
• Cupronickel	• Nanocrystalline oxide thin films	
• Cu-Zn and Cu-Al alloys	• Ni base alloy NiCr hardface	
• Ductile Iron	• Nickel	
• Duplex Stainless Steel	• Nickel Base Alloy	
• Fe-Al Intermetallics	• Nickel Base Superalloy	
• Ferritic Steel	• Nickel Iron Base Superalloy	
• Glass Ceramic	• Niobium Alloys	
• Glass polymer multilayer composite	• Nitriding	
• GTAW –Ni base alloy	• Ni-W alloy	
• Hard Coating	• Oxide	
• High Tc Superconductors	• Oxide Multilayers	
• HSLA Steel	• Refractory Metals	
• Intermetallics	• Silica glass	

Table 1: List of Materials in the Database

The Properties of materials found in the database is listed in the table-2 below.

ACOUSTIC EMISSION	HIGH TEMPERATURE CORROSION	SOLIDIFICATION STRUCTURE
ADHESION	HIGH TEMPERATURE OXIDATION	STRESS CORROSION
BALLISTIC	HYDRIDE BLISTER FORMATION	STRUCTURAL
BIODEGRADATION	HYDRIDE EMBRITTLEMENT	SUPERCONDUCTIVITY
BIOFOULING CONTROL	HYDROGEN TRANSPORT	SUPERPLASTICITY
BIOFOULING CONTROL LRS STUDY	IMPACT	TENSILE
BIOFOULING CORROSION	INDENTATION FATIGUE	THERMAL
BIOFOULING DETECTION	LOW CYCLE FATIGUE	THERMO MECHANICAL FATIGUE
BIOFOULING DETECTION WITH LRS	LOW TEMPERATURE EMBRITTLEMENT	TRIBOLOGICAL
COMPRESSION	LOW TEMPERATURE SENSITIZATION ON IGSCC	ULTRASONIC
CORROSION	MAGNETIC FLUX LEAKAGE	ULTRASONIC SPECTROSCOPY
CORROSION BEHAVIOUR	MICRO STRUCTURAL STUDIES	UNIFORM
CREEP	MICROBIAL CORROSION	WEAR
CREEP CRACK GROWTH	MICROHARDNESS	X-RAY BASED DIFFRACTION TECHNIQUES
CREEP FATIGUE	MULTIAXIAL FORGING	
DELAYED HYDRIDE CRACKING	NANOMECHANICAL	
DIELECTRIC	OPTICAL	
DISTORTION	OXIDATION	
DYNAMIC FRACTURE TOUGHNESS	PITTING CORROSION	
EDDY CURRENT TESTING	PROCESS PARAMETERS	
ELECTRICAL	PROPERTIES OF WELD	
FAILURE ANALYSIS STUDIES	QUASI STATIC FRACTURE TOUGHNESS	
FATIGUE	REPAIR WELD	
FATIGUE CRACK GROWTH	RESISTIVITY	
FRACTURE TOUGHNESS	SENSITIZATION	
FRETTING	SHEAR STRESS	
FRETTING FATIGUE	SODIUM CORROSION	
FRETTING WEAR		
HARD FACING		
HARDNESS		
HIGH CYCLE FATIGUE		

Table 2 : List of Properties of materials in the Database

Ferritic Steel	Nickel	Titanium Alloys	Austenitic Stainless Steel
1Cr-0.5 Mo Steel	1Fe-16%Al	304L SS+Ti Explosive Joint	304 L
2.25Cr-1Mo	1Fe-16%Al-1%C	304L SS+Ti Friction Joint	304 L rupture disc
2.25Cr-1Mo/9Cr-1Mo	720 Li	Commercial Purity-Titanium	304 L,304 LN
2.25Cr-1Mo/alloy 800	IN 718	CP Grade 2 Titanium	304 LN
9Cr-1Mo	IN 718 Weld	CP-Ti	304 SS
9Cr-1Mo and 2.25 Cr-1Mo Steel weld joint	Inconel 718- EN24 weld	IMI 834	316 L(N) SS
9Cr-1Mo and 2.25 Cr-1MoSteel	Ni 3% W/Ni-10% Cr, 1.5% Al	Near Alpha Ti alloy IMI–834	316 LN SS electrode
9Cr-1Mo Steel	Nickel	Ti-5Ta	316 SS
9Cr-1Mo/ 2.25 Cr-1Mo Dissimilar	Nickel Base Superalloy 720 Li	Ti-5Ta-1.8 Nb Base Metal	316 SS Weld Metal
Aged 9Cr-1Mo		Ti-5Ta-1.8Nb	316 Stainless Steel TIG welds
G-911 steel		Ti-5Ta-1.8Nb alloy	316(L) Weld Metal
Mod. 9Cr-1Mo		Ti-5Ta-1.8Nb Weld Metal	316(N) Weld Metal
Mod. 9Cr-1Mo steel		Ti-5Ta-1.8Nb Weldment	316L
Mod. 9Cr-1Mo Steel- Base Metal		Ti-6Al-4V	316L BaseMetal
Modified 9Cr-1Mo		Ti-6Al-4V TIG weldments	316L(N)
modified 9Cr-1Mo grade91 weld joint		Ti-6Al-4V weld metal	316L(N) / 316 Weld Joint
modified 9Cr-1Mo Steel grade 91		Ti-6Al-4V weldments	316L(N) Base Metal
modified 9Cr-1Mo Steel grade 91,70mm forge		TIMET 834	316L(N)2
Modified 9Cr-1Mo Weld Joint		TiMetal 685	316LN BaseMetal
Modified 9Cr-1Mo Weld Metal		Titanium Ti- 6Al-4V	316LN Weld Joint
RAFM steel			316LN Weld Metal
SA 333 grade 6			316LN(3)
			316LN(3) Weld Metal
			316LNH
			AISI 304
			AISI 304 Stainless Steel
			Alloy 625
			D9
			Nimonic PE-16
			Nitrogen Alloyed Austenitic Steels
			Uranus-65 NAG SS

Table 3: List of Materials type in the Database

Sample Material sub types of Ferritic Steel, Nickel, Titanium Alloys and Austenitic Stainless Steel are given in the table-3 below.

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Chapter 5: Summary and Recommendations

The material database is rich with data. The database presently consists of 60 materials along with 275 material subtypes. There are 72 properties listed against the material subtypes. This data pertains to more than 500 journal data. The test conditions used is in the range of 520, around 1533 graphs and 1710 microstructures are available in the database.

The database can be categorized as the open science initiative, since the data pertaining to the research output along with the selection criteria which includes the material type, properties tested, the test cases used, the standard used, etc., are included for download. Government of India has to take initiatives for all institutes to store their respective data in a common centralized repository for research scholars, industries and students to use for research purpose in FAIR mode.

The website is listed in Google to increase its visibility. The website is hosted in the NIC cloud from 2017. The website has a visitor count of 43506. Certain materials data on "Use of Eddy Current Testing Method in Detection and Evaluation of Sensitization and Intergranular Corrosion in Austenitic Stainless Steels" are downloaded up to 236 times.

The website was developed in-house using MySQL and ASP.Net. To host the website in NIC, the data web application has to be audited every three years or whenever a correction is made for web application security. Henceforth, the materials database will be stored in the institutional repository of IGCAR.

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Research Summary

Project entitled "Setting up of Indian Material Database for Scientists, Engineers and Industries" by Smt S. Rajeswari, Indira Gandhi Centre for Atomic Research, Kalpakkam 603 102, Department of Atomic Energy, Tamilnadu between May 2017-April 2020

Indira Gandhi Centre for Atomic Research with funding and support from CHORD, NSTMIS, DST, has developed Materials Database of India by bringing together the materials property research data from different organizations in India and collating into a database. Indian laboratories generate research data on Mechanical, Corrosion, Non-destructive Evaluation, Thermal and Optical properties of materials used in power, space, nuclear and chemical industries as per international ASTM standards. This project is a pioneering attempt to compile such research data and make it available to the scientific community to reuse without repeating the same experiments. A unique feature of this data storage will be its authenticity since it solely consists of data published in reputed peer-reviewed publications.

The materials database was implemented using a multi-dimensional database model. Material database visibility is enhanced by providing searches on materials class and material property data. Data also includes the name of the journal, citation, etc. Further, the data are available in the form of tabular data, graphs and microstructures.

The database presently consists of 60 materials and 275 material subtypes with 72 properties and more than 500 journal data. The test conditions used is in the range of 520 with around 1533 graphs and 1710 microstructures are part of the database.

Many institutes participated in the project and provided their research data. They are Bhabha Atomic Research Center (BARC), National Metallurgical Laboratory (NML), Research and Development Centre for Iron and Steel (RDCIS), Central glass and Ceramic Research Institute (CGCRI), Indian Institute of Technology, Roorkee, (IITR), Indian Institute of Technology, Kanpur,(IITK), Visvesvaraya National Institute of Technology (VNIT), National Institute of Technology, Karnataka (NITK), Indian Institute of Technology, Madras, (IITM) and IGCAR.

The materials database of India is available with IGCAR in the institutional repository for further reference.

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