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A DATA BASE FOR AGING OF STRUCTURAL MATERIALS

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ABSTRACT

The U.S. Nuclear Regulatory Commission (USNRC) initiated a Structural Aging (SAG) Program at the Oak Ridge National Laboratory (ORNL). The objective of the program is to provide assistance in identifying potential structural safety issues and to establish acceptance criteria for use in nuclear power plant evaluations for continued service. One of the main parts of the program focuses on the development of a Structural Materials Information Center where long-term and environment-dependent material properties are being collected and assembled into a data base. This data base is presented in two complementary formats. The *Structural Materials Handbook* is an expandable, hard-copy reference document that contains the complete data base for each material. The *Structural Materials Electronic Data Base* is accessible using an IBM-compatible personal computer. This paper presents an overview of the Structural Materials Information Center and briefly describes the features of the handbook and the electronic data base. In addition, a proposed method for using the data base to establish current property values for materials in existing concrete structures and to estimate the future performance of these materials is also presented.

1 INTRODUCTION

Material properties, data, and information for structural materials typically used to construct reinforced concrete structures in nuclear power plants are being collected and assembled into a data base at the Structural Materials Information Center. Descriptive information, compositional characteristics, baseline data, reference values, and processing parameters for each material are included along with at least one time-dependent or environment-dependent material property. The need for this type of data base was established in a report on concrete component aging and its significance relative to the life extension of nuclear power plants [1]. A review of materials property data bases [2] revealed that no data bases existed that met the needs of the SAG Program.

Material properties, data, and information collected at the Structural Materials Information Center are presented in two complementary formats. The *Structural Materials Handbook* is an expand-

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able, hard-copy reference document that contains complete sets of data and information for each material in the data base and serves as the information source for the *Structural Materials Electronic Data Base.* The electronic version provides access to the data using a data base management software system that operates on an IBM-compatible personal computer. Reports describing the development of the Structural Materials Information Center [3] and the formats being used to report data and information in the handbook [4] have been prepared. Examples of how the material properties in the data base could potentially be used to assist in performing current or continued service assessments of reinforced concrete structures in nuclear power plants [5] have also been developed. The data base currently includes properties for the materials listed in Table 1. The data and information included in the handbook and the electronic data base are presented using the International System (SI) of Units and customary units.

Table 1. Types of materials available from the Structural Materials Information Center.

Material Type	Presentation Format	
	Structural Materials Handbook Volumes 1, 2, and 3	*Structural Materials Electronic Data Base* File Name
Portland Cement Concrete	Chapter 01	CONCRETE.DB
Metallic Reinforcement	Chapter 02	REBAR.DB
Prestressing Tendon	Chapter 03	TENDON.DB
Structural Steel	Chapter 04	STEEL.DB
Rubber	Chapter 05	RUBBER.DB

2 STRUCTURAL MATERIALS HANDBOOK

The *Structural Materials Handbook* consists of four volumes that are published in loose-leaf binders. Volume 1 contains design and analysis information useful for structural assessments and structural margins evaluations. This volume contains performance curves for mechanical, thermal, physical, and other properties presented as tables, graphs, and mathematical equations. Volume 2 reflects the supporting documentation and includes test results and data used to develop the performance curves presented in Volume 1. Material data sheets are provided in Volume 3. These sheets include general information, baseline data, and reference values as well as material composition and constituent material properties. Volume 4 contains appendices that describe the handbook organization, updating and revision control procedures, and electronic data base accessing information. Each chapter in Volumes 1, 2, and 3 is organized to include the materials property data base for a particular type or category of material. As shown in Table 1, Chapter 1 addresses portland cement concretes; Chapter 2, metallic reinforcements; Chapter 3, prestressing tendons; Chapter 4, structural steels; and Chapter 5, rubbers.

Each material in the data base is assigned a unique seven-character material code which is used in the handbook and the electronic data base to organize materials with common characteristics. This code consists of a chapter index, a group index, a class index, and an identifier. The chapter index is used to represent the various material systems in the data base. The group index is used to arrange materials in each chapter into subsets of materials having distinguishing qualities such as common compositional traits. The class index is used to organize groups of materials with common compositional traits into subsets having a similar compositional makeup or chemistry. The identifier is used to differentiate structural materials having the same chapter, group, and class indices according to a specific concrete mix, ASTM standards for metallic reinforcement, etc.

A wide variety of descriptive information and materials property data are contained in the data base as tables, notes, and graphs. In order to organize the data base, each entry is assigned a unique four-digit property code selected from an established set of material property categories. The property code ranges and corresponding material property categories are used consistently in the handbook and the electronic data base. Volumes 1 and 2 are formatted so that the performance curves and supporting documentation reported on each page correspond to the property code that appears in the page heading. Volume 3 is formatted so that the information and data presented on each material data sheet correspond to a particular property code range (e.g., 1000–1999, 2000–2999, etc.). Since each material data sheet can include combinations of general information, constituent material, plastic concrete, mechanical, thermal, physical, and other properties, these pages are formatted to contain information and data that pertain to only one particular property code range.

Each reference document that is used as an information source at the Structural Materials Information Center is assigned a unique integer identifier. This number and the reference source that it represents are used synonymously in the data base. Since each reference is used in Volumes 1, 2, and 3 and may be used for more than one property or structural material, a complete list of all references used in the handbook appears in Appendix E of Volume 4.

3 STRUCTURAL MATERIALS ELECTRONIC DATA BASE

The *Structural Materials Electronic Data Base* operates on an IBM-compatible personal computer using a commercially-available data base management system [6]. This system of hardware and software provides access to material properties data and information contained on electronic data base files. The electronic data base management system includes two software programs: Mat.DB [7] and EnPlot [8]. These programs are available from ASM INTERNATIONAL, Materials Park, Ohio. Each software package includes a user's manual and program disks. The user's manuals for the data base management system contain specific instructions for formatting, entering, searching, and displaying data and information. The electronic data base files identified in Table 1 were developed at the Structural Materials Information Center using Mat.DB and EnPlot.

Mat.DB is a menu-driven software program that employs window overlays to access data searching and editing features. This software is capable of maintaining, searching, and displaying textual, tabular, and graphical information and data contained in electronic data base files. Mat.DB is well suited for metallic materials and can accommodate nonmetallic and composite materials such as portland cement concrete. The instructions in the user's manual provide procedures for entering data and information into electronic data base files and for customizing presentation formats.

EnPlot is a software program that incorporates pop-up menus for creating and editing engineering graphs. This software includes curve-fitting and scale-conversion features for preparing engineering graphs and utility features for generating output files. The engineering graphs that appear in the electronic data base files and the graphs that appear in Volumes 1 and 2 of the handbook are developed using this software.

4 INFORMATION SOURCES

One of the findings from the review and assessment of materials property data bases [2] was that documented long-term and environment-dependent material properties for concrete are limited.

This is especially true for concretes subjected to aging factors and environmental stressors associated with nuclear power plants. For most concrete structures that have been in service for the time period of interest (30–100 years), either detailed information about constituent materials, plastic concrete properties, curing procedures, and exposure conditions are not available, or the time variation of material properties is unknown.

Since these types of data and information are not readily available, two approaches are being used to supplement and expand the data base. One approach focuses on pursuing technical information exchanges with U.S. and foreign research establishments. The other approach concentrates on the development of properties using prototypical material samples obtained from existing concrete structures. Research establishments in the U.S., Canada, Japan, and Europe have been contacted in an effort to obtain materials property data and information for input into the Structural Materials Information Center. In the U.S., Canada, and Japan, selected governmental agencies that are responsible for design, maintenance, and repair of concrete structures have been contacted along with universities and private research organizations that perform material properties tests on concrete and other structural materials [9]. In Europe, various types of organizations in the Federal Republic of Germany, Switzerland, Denmark, and England have been visited [10], and site visits to different Canadian and Japanese research establishments have been conducted [11 and 12]. Several U.S. electrical utilities, a national laboratory, and a concrete research organization have been contacted to pursue the possibility of obtaining concrete core samples from prototypical structures [9]. However, for these samples to be useful, baseline data, reference properties, and environmental information must also be provided so that a complete data base for the material can be developed. So far, four sets of concrete core samples and corresponding construction documents and test records have been obtained from nuclear-related facilities that have been in service for approximately 30 years.

5 POTENTIAL APPLICATIONS

The structural integrity of a concrete structure can be evaluated using either a load test or an analytical approach. A recommended procedure for conducting a strength evaluation of existing concrete buildings has been established by ACI Committee 437 [13]. The structural integrity of an existing concrete structure can also be evaluated using an analytical approach which involves a theoretical stress analysis. This analysis must take into account the physical characteristics of the structural members and their connection details, material properties, the quality of construction, and the present condition of the structure. For this analysis to be reliable, properties of the materials in their current condition within the structure must be obtained and used. Typically, two methods are available to obtain these properties. One method relies on nondestructive testing techniques. When test instruments are calibrated or certified and standardized procedures are used, this method can provide the needed properties. The other method requires that material samples be removed from the structure for testing. Visual examinations combined with destructive and nondestructive testing can also be used to characterize the overall condition of the materials in a structure. Inspections, sampling, and nondestructive testing are not feasible, however, unless the structural components are accessible.

A third way to obtain the properties needed for a theoretical stress analysis uses a comparative approach. In this approach, the performance characteristics of other materials that have been exposed to similar service or environmental conditions are used to establish properties for materials in an existing structure. This approach can be used for almost any structure because it does not require removal of material samples or access for nondestructive testing. In nuclear power plants where in many areas access to structural concrete components is restricted or removal of material samples is prohibited, this approach may be the only feasible way to establish the needed properties. This approach has been used successfully in conjunction with material sampling and nondestructive testing to obtain mechanical properties for use in evaluating the structural integrity of fire-damaged reinforced concrete walls in a nuclear power plant [14], and in the development of a standard test method for comparing concretes on the basis of the bond developed with reinforcing steel [15].

Establishing material properties using the comparative approach requires a large knowledge base of long-term and environment-dependent material behavior such as the one being developed at the Structural Materials Information Center. The data and information in this structural materials property data base have been formatted so that materials with similar compositions and similar baseline or reference properties can be easily identified for comparison. Procedures for using the data base to establish current property values for materials in existing concrete structures and for estimating the future performance of these materials have been established [5] and are described below.

A step-by-step procedure for establishing current property values for materials in an existing concrete structure is listed below. This procedure should only be used as a guide, however, because each concrete structure has unique characteristics and features, and each theoretical stress analysis must be performed on a case-by-case basis.

1. Collect background information so that the structural materials in the existing structure can be uniquely identified.
2. Establish the service history for each structural material.
3. Identify the types of material properties needed for the theoretical stress analysis.
4. Search the data base to identify materials with compositions, characteristics, and exposure conditions similar to the materials in the structure.
5. From the properties reported for these materials, select properties that adequately reflect the service history of the materials in the existing structure.
6. Using the performance curves in Volume 1 and the supporting documentation in Volume 2 of the *Structural Materials Handbook* reported for these properties, establish numerical values for each property needed for the theoretical stress analysis.

A step-by-step procedure for estimating future properties of materials is listed below. This procedure is applicable to structural materials in existing concrete structures that are required to remain in service for a specified period of time.

1. Establish current properties for the structural materials in the existing structure using the procedure described above.
2. Establish the continued service period, and predict the service conditions for each structural material during this continued service period.
3. From the properties reported in the data base for these materials, select properties that adequately reflect the continued service period and the predicted service conditions for the structural materials in the existing structure.
4. Using the performance curves in Volume 1 and the supporting documentation in Volume 2 of the *Structural Materials Handbook* reported for these properties, establish numerical values for each property at the end of the continued service period.

6 SUMMARY

A materials property data base is being developed at the Structural Materials Information Center. This data base is presented as the *Structural Materials Handbook* and the *Structural Materials Electronic Data Base* and contains data and information on portland cement concrete, metallic reinforcement, prestressing tendon, structural steel, and rubber materials. The handbook is an expandable reference document that contains the complete data base for each material. The electronic data base is provided on diskettes and is accessible using an IBM-compatible personal computer. The data base includes data and information on long-term and environment-dependent material properties obtained from technical information exchanges and from tests conducted on prototypical samples removed from existing concrete structures. Properties are reported in the International System (SI) of Units and in customary units whenever possible.

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