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Acquisition of long-term creep data and knowledge for new applications☆

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Abstract

This paper introduces the activities being conducted by the National Institute for Materials Science (NIMS) to acquire long-term creep-test data on heat-resistant steels and alloys, as well as some study results on the creep strength of heat-resistant steels and alloys, obtained through the NIMS Creep Data Sheet project. The results emphasize the importance of data acquisition in conducting long-term creep tests and the need for a comprehensive understanding of changes in metallurgical microstructure, creep deformation, damage formation and growth, and creep rupture life, and the relationships among these factors. The importance of establishing international cooperation in data and information sharing, in order to prepare for the globalization of society, is stressed.

Keywords: Heat-resistant steels and alloys; Creep rupture strength; Microstructure; Creep deformation; Life prediction; Aged plants; High-Cr ferritic steels; Allowable stress; NIMS Creep Data Sheet

1. Introduction

Approximately 80 years have passed since creep problems were first taken into consideration in the design of high-temperature plants because of rises in operating temperature. Approximately 30–50 years have passed since the time when heat-resistant steels and alloys were standardized in Japan and other countries, and their creep-test data were obtained and made publicly available. Substantial amounts of creep-test data on heat-resistant steels and alloys have now been accumulated globally. However, our present rate of acquisition of long-term creep-test data on these materials and the amount of accumulated knowledge that we have are still insufficient for improving our accuracy of evaluating the lives of plants used for a long time. They are also insufficient for ensuring the safe use of the newly developed high-temperature heat-resistant materials and thus the alleviation of global environmental problems. Various organizations and institutions in many countries have made strenuous efforts to obtain these long-term creep-test data and are still continuing their efforts. However, because of the lack of sufficient funds and manpower for inputting information into their data acquisition activities, and because of other various problems, such as limitations in facility maintenance and insufficient resources, the activities of these organizations have either declined or been suspended. It is extremely important that we obtain long-term creep-test data on heat-resistant materials. The accumulation of knowledge on these materials is indispensable for securing the safety and improving the reliability of high-temperature plants. In particular, these long-term creep-test data form the basis of the drive to secure the safety and improve the reliability of high-temperature plants. Efforts to obtain these data must be continued.

This paper describes past activities to obtain long-term creep-test data and gives an introduction to the present data acquisition activities, in particular, the present status of the Creep Data Sheet project of the National Institute for Materials Science (NIMS). The paper also emphasizes the importance of acquiring long-term creep-test data in view of the results obtained thus far from the Data Sheet project. I also offer my own opinion on the need for future international cooperation in acquiring long-term creep-test data on heat-resistant materials.

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2. Need to acquire long-term creep-test data

An understanding of the creep-strength characteristics of structural materials is inevitable for securing the safety of thermal power plants and petrochemical plants that are operated under high temperatures. These thermal power plants and petrochemical plants are used for long periods of time—approximately 20–30 years. These plants are generally designed on the basis of a creep rupture strength of 100,000 or 200,000 h. However, as it is difficult to acquire a large number of long-term creep-test data, the allowable creep strength for plant design is obtained by extrapolation from short-term creep-test data. The intention is to review the allowable creep strength when the long-term creep-test data become available in the future, if there are any problems. The extrapolation method is used to obtain the allowable creep strength by accelerating the rupture life of the material of concern by increasing the test temperature. Although many extrapolation methods of obtaining the allowable creep strength have been proposed, there are as yet no perfect ones. Therefore, the rupture life of the material concerned, as predicted by the extrapolation method, must still be verified by long-term creep tests.

The number of aged thermal power plants and petrochemical plants, not only in Japan but also globally, has recently increased. Thus, it is necessary to improve the reliability of the method of predicting the remaining lives of these plants. To do this, it is necessary to clarify the changes in metallurgical microstructure during a long period of creep progress, as well as the creep damage and fracture mechanisms and their effects on material life.

The creep strength of a metal is a very sensitive characteristic of metallurgical microstructure. The creep-strength characteristics of a metal vary greatly, depending upon slight changes in chemical composition of the metal and the conditions of rolling or heat treatment. The extent of the effects of these elements is not yet completely known, and there are many unknown factors that may affect these characteristics. For these reasons, the creep-strength characteristics of engineering materials should be examined on the basis of the test data on these materials.

3. Trends in data acquisition activities

3.1. The global situation

Most of the heat-resistant steels that are presently used in high-temperature plants were developed before, or during, World War II. These steel materials were internationally standardized after the war. The method used at present to determine the creep-related allowable strength of steels was decided upon in 1950 by the standards of the American Society of Mechanical Engineers (ASME), a body that strongly influenced the design of high-temperature plants.

As a result, long-term creep tests were conducted in various countries and the test results were made public as creep data sheets over a period from the 1960s to the 1970s. The representative ones are the ASTM data series, the British Steelmakers Creep Committe (BCCC) high-temperature strength data series, and the long-term data series of the Iron and Steel Institute of Germany [1]. Creep data acquisition activities were most active during the 1970s. After that period, systematic data acquisition activities declined. Some organizations and institutions are independently conducting creep tests to acquire the necessary data, but those data are not widely publicly available.

In Japan, it became necessary among industries during the 1960s to certify that domestically developed heat-resistant steels and alloys had met international standards. For this purpose, the facilities and equipment necessary for conducting long-term creep tests of heat-resistant steels and alloys were built at the National Research Institute for Metals (NRIM). The NRIM Creep Data Sheets project began in 1966. The project continues under the auspices of the NIMS, the renamed NRIM. NIMS is one of the world's representative research institutes conducting large-scale long-term creep tests of heat-resistant steels and alloys.

3.2. New developments in Europe

In Europe, the European Creep Collaborative Committee (ECCC) was established in 1992 to promote research on the creep of heat-resistant materials for the whole of Europe. The purpose of the establishment of the ECCC was to acquire, collate, and analyze creep data on the steels and alloys to be used in high-temperature plants, with the cooperation of various organizations and institutes. ECCC presently has 14 member countries. The objectives of ECCC are to acquire creep data, to set up standards for creep strength, and to reflect the acquired data in the design values of European Standards.

As mentioned above, it is necessary to input a large amount of resources to conduct long-term creep tests. Thus, the dispersal of creep tests over various locations, as done by the ECCC, is a good idea for creep-test data acquisition under international cooperation. However, if we compare the creep-test data that are obtained by various organizations, it is evident that there are deviations in the data obtained by different organizations. The factors influencing creep tests are load and temperature. Provided that the traceability of load and temperature is observed, there should not be deviations from organization to organization. However, in reality, there are variations in data from organization to organization. In other words, when data obtained by several organizations are being used for analyses, the uncertainty of the deviation between organizations is included in the analyses.

Although there are some problems involved in such cooperative data acquisition, this is a good method of efficiently acquiring data under international cooperation. It is very important that we learn from the method used by the ECCC.